Development & Application of NorWeST Stream Temperature Scenarios for PNW Streams

Dan Isaak, Seth Wenger[1], Erin Peterson[2], Jay Ver Hoef[3] Charlie Luce, Steve Hostetler[4], Jason Dunham[4], Jeff Kershner[4], Brett Roper, Dave Nagel, Dona Horan, Gwynne Chandler, Sharon Parkes, Sherry Wollrab, Colete Bresheares, Neal Bernklau

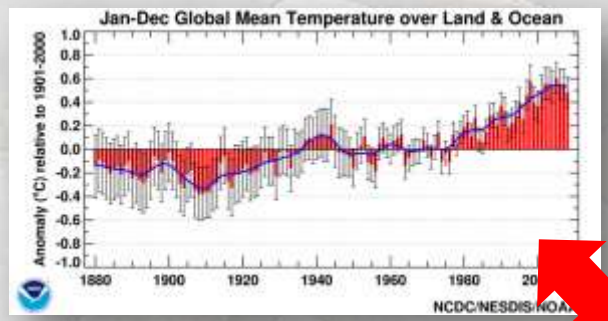
U.S. Forest Service

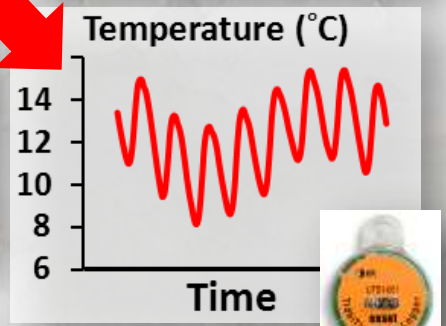
[1]Trout Unlimited

[2]CSIRO

[3]NOAA

[4]USGS



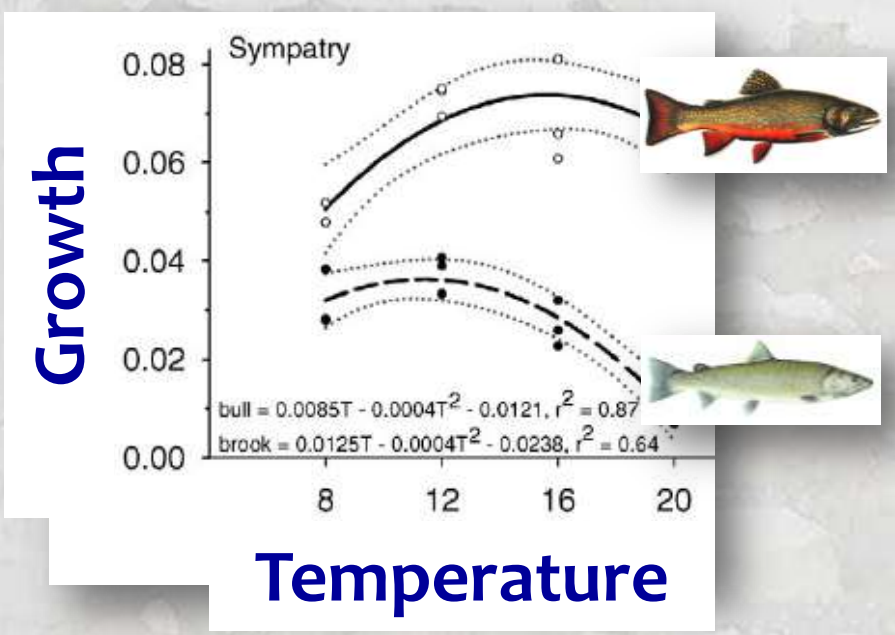


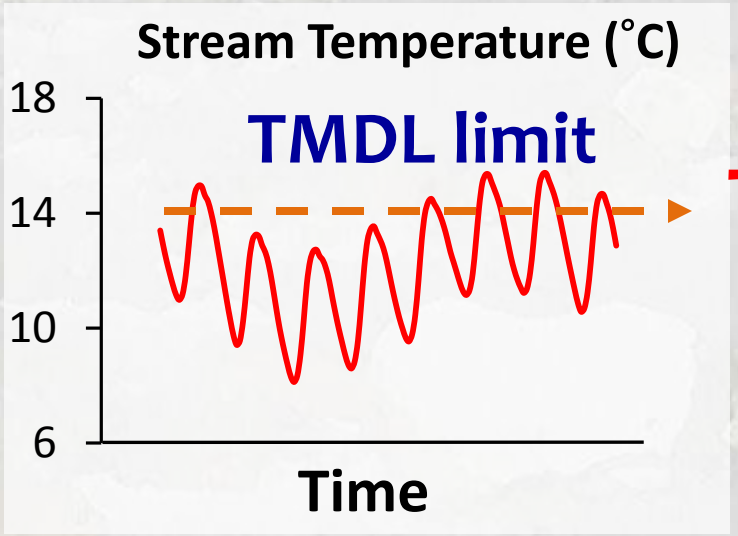
General outline:

1) Background & stream temperature trends
2) NorWeST model & scenarios
3) Uses of NorWeST scenarios
4) Future expansion of NorWeST

Stream Temperature is "Climate" in Streams

Master variable for ectotherms

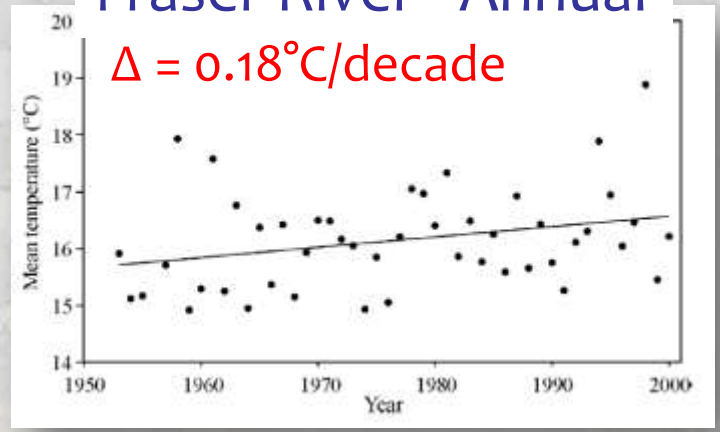




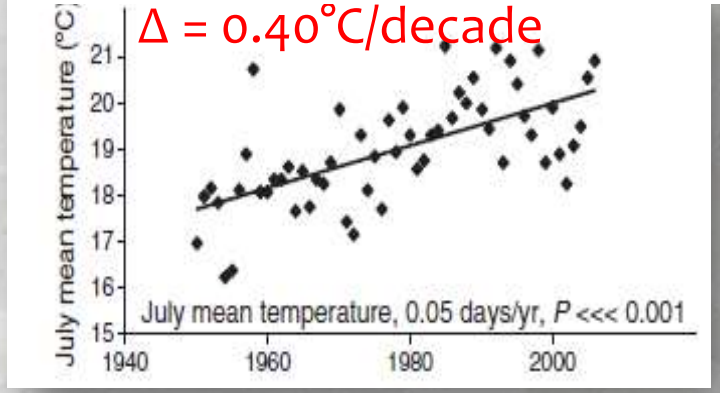
Too Hot!

Temperature Trends In Northwest Rivers

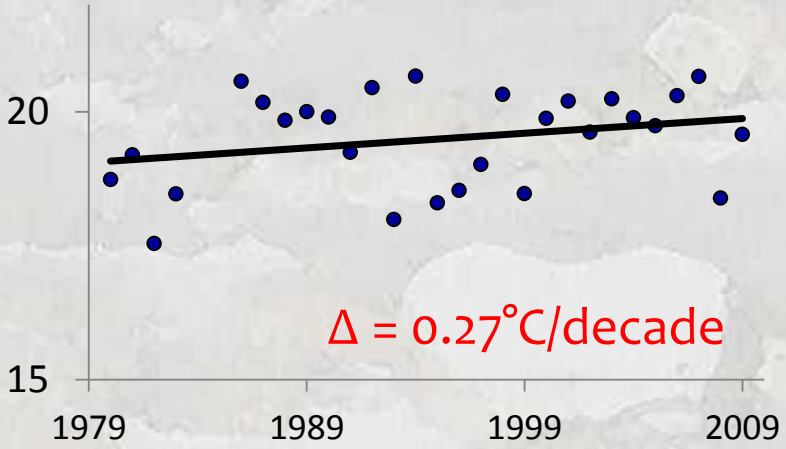
Fraser River - Annual



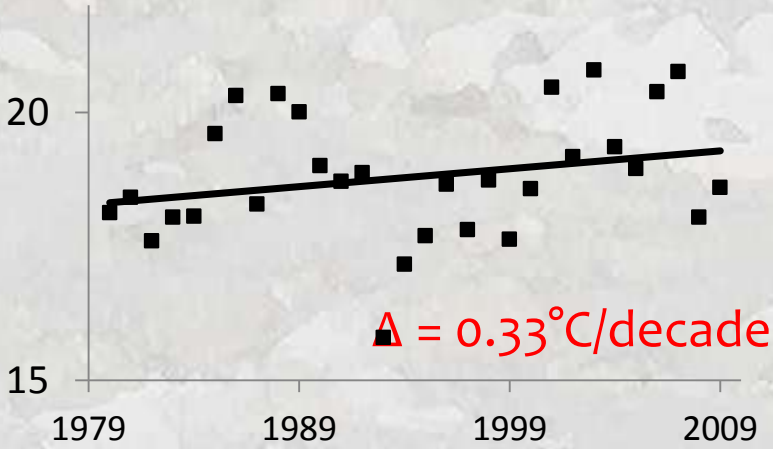
Columbia River - Summer



Snake River, ID - Summer

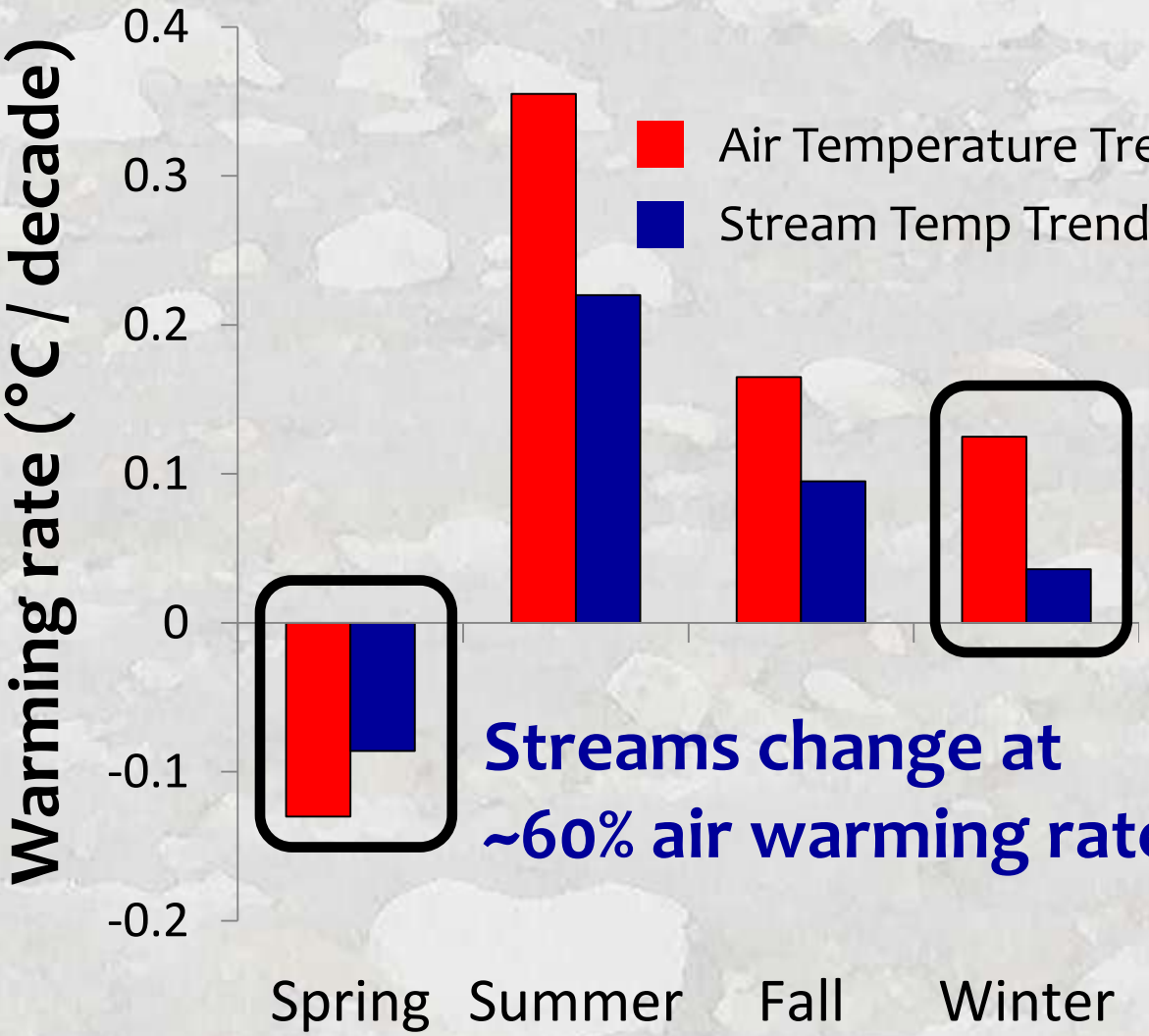


Missouri River, MT - Summer



Stream Temperature Trends Track Air Trends at Local Weather Stations

1980-2009



Streams change at ~60% air warming rate

Weather Station Data

Isaak et al. 2012. *Climatic Change* **113**:499-524.

Stream Temperature Trends Track Air Trends at Local Weather Stations

1980-2009

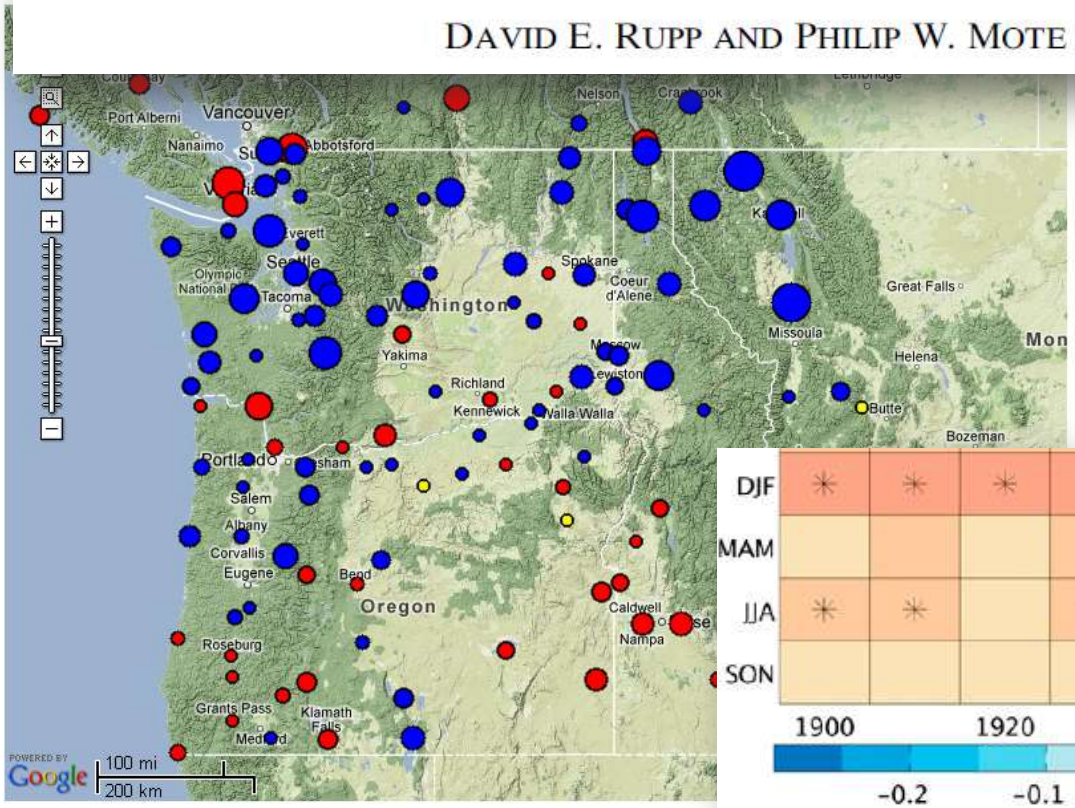
0.4

Seasonal Climate Variability and Change in the Pacific Northwest of the United States

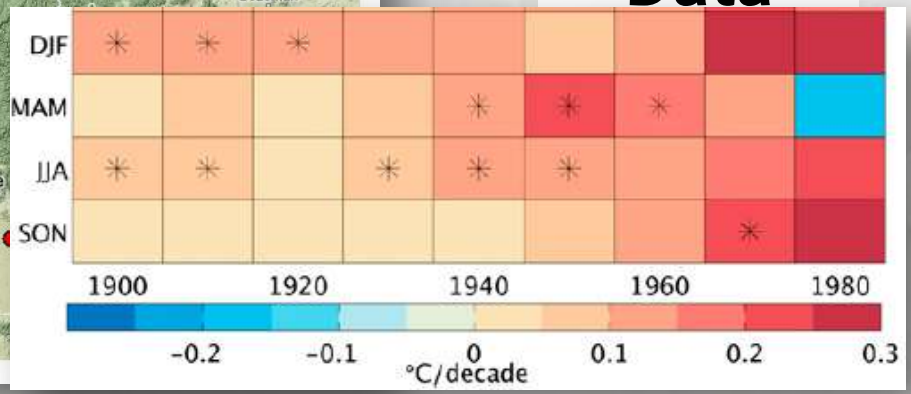
JOHN T. ABATZOGLOU

Department of Geography, University of Idaho, Moscow, Idaho

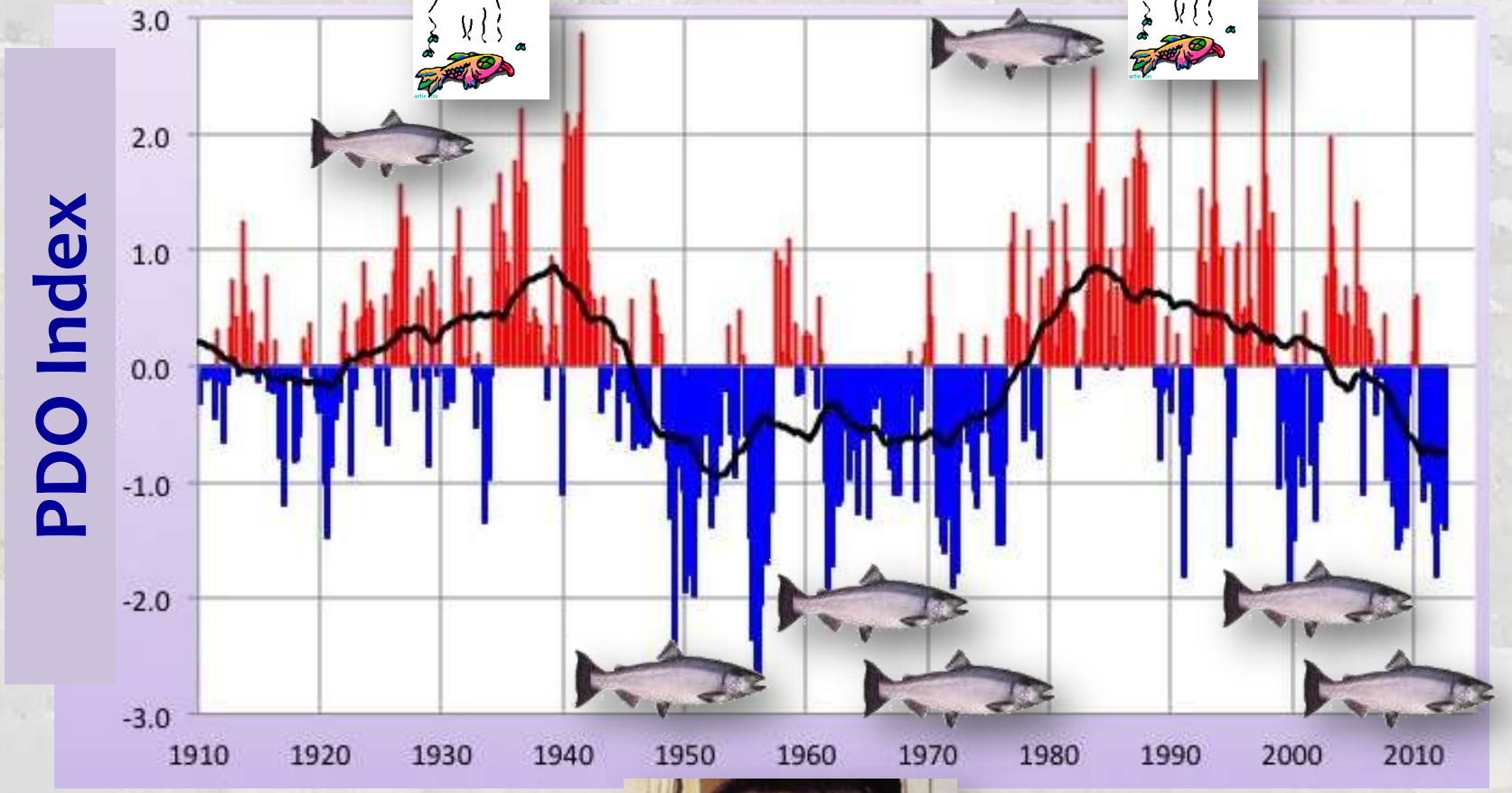
DAVID E. RUPP AND PHILIP W. MOTE



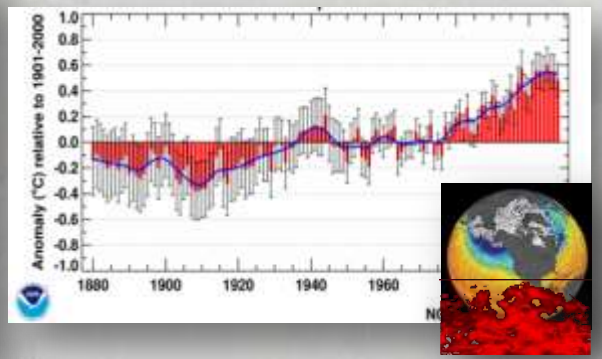
Weather Station Data



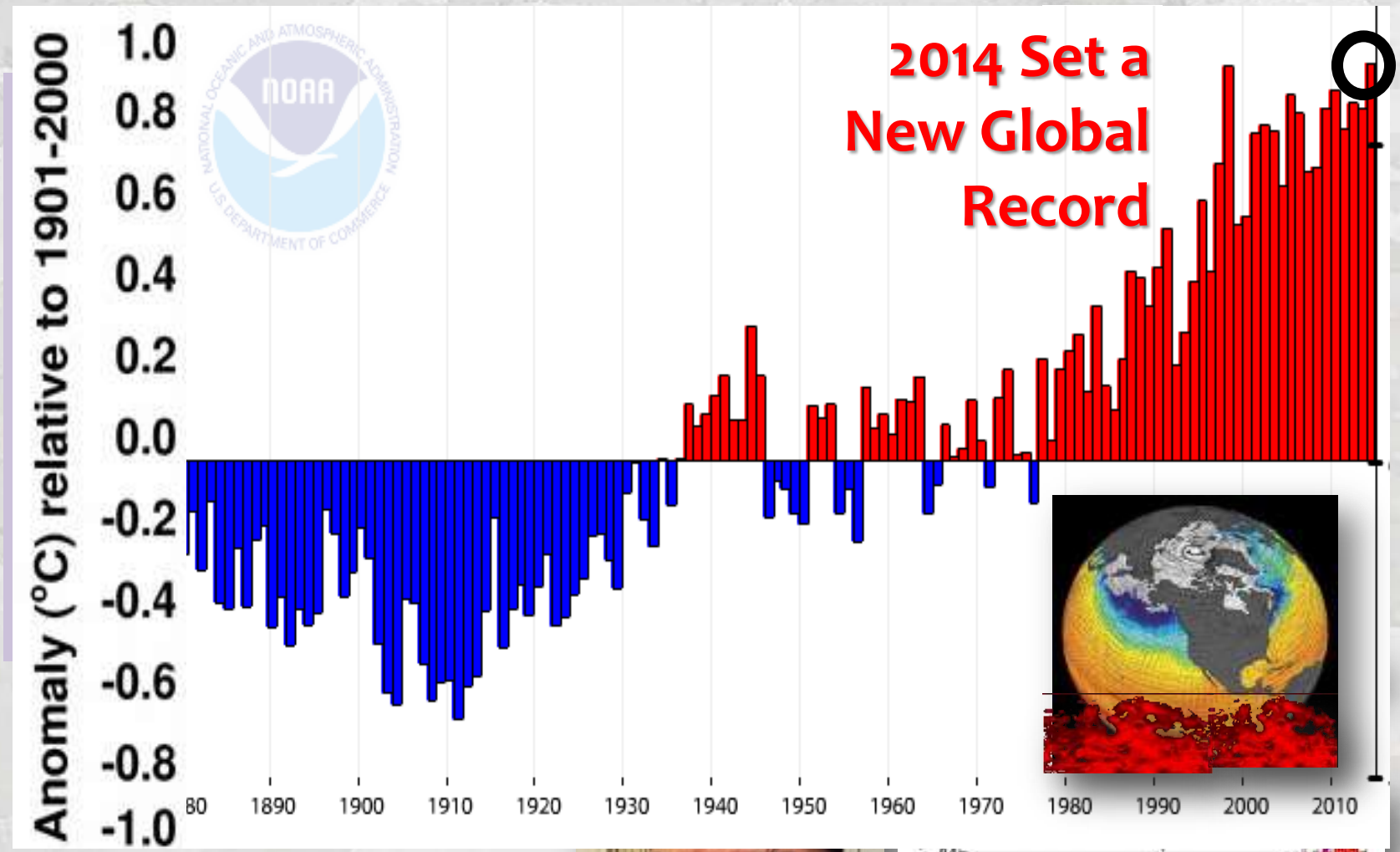
PDO Is Buying us Time…



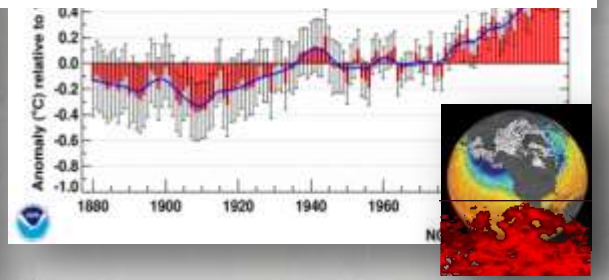
"but I'll be Back…"



PDO Is Buying us Time…

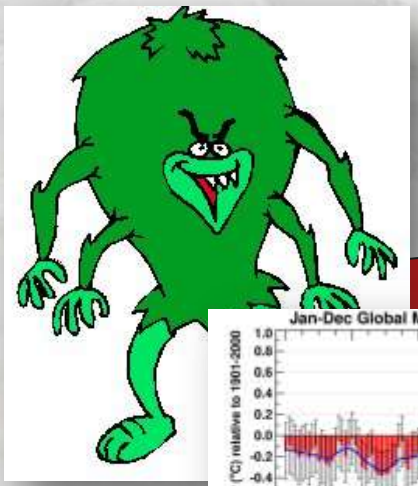


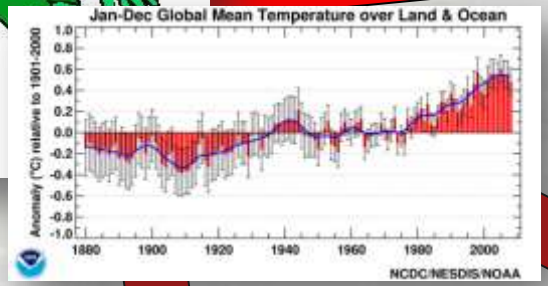
"but I'll be Back…"



There's A Lot on the Line…

Climate Boogeyman





Tribal & Recreational Fisheries

ESA Listed Species

Land Use & Water Development

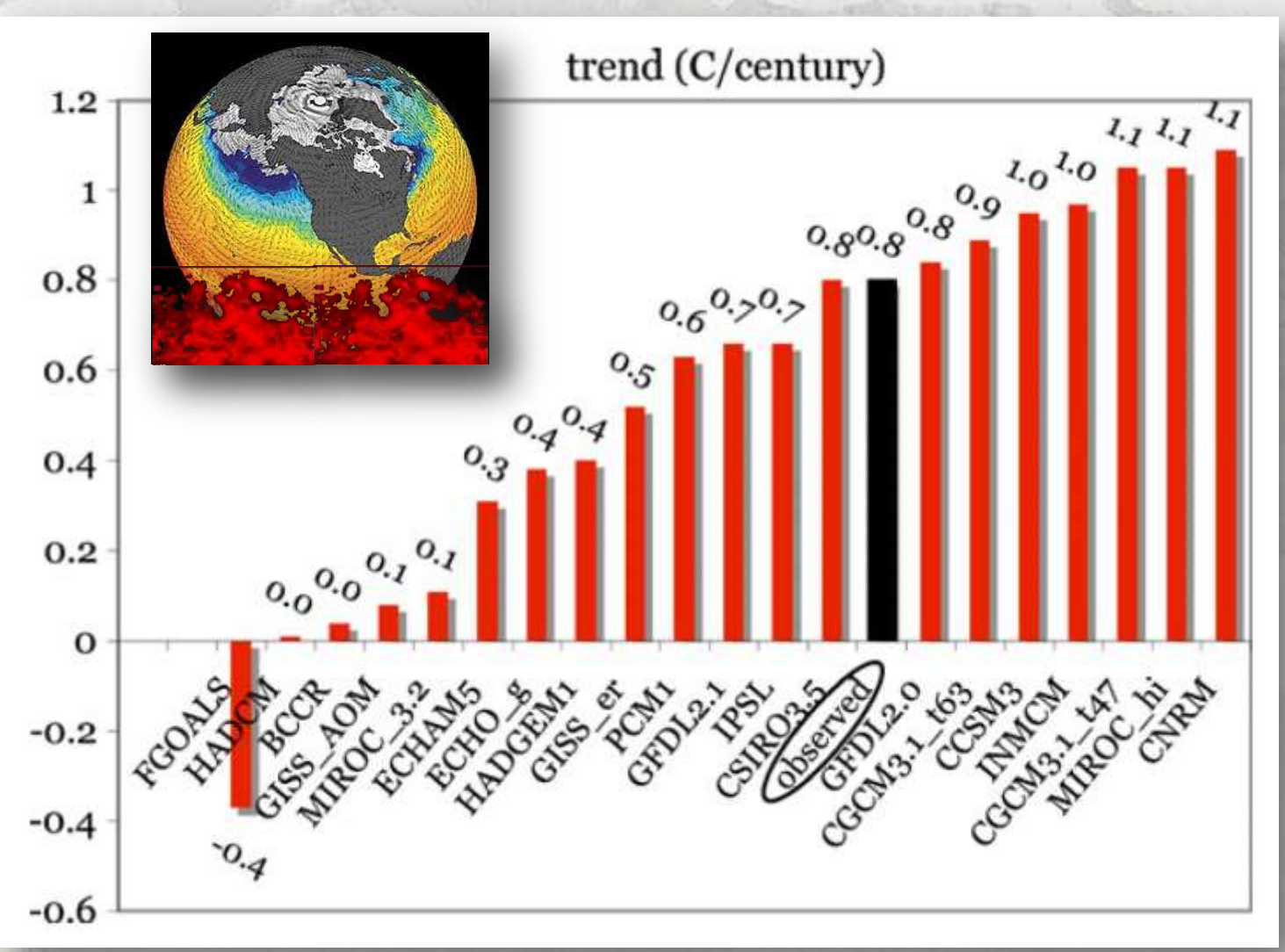
Good News! Lots of Things we Can do to Improve Stream Habitat Resilience

- Maintaining/restoring flow…
- Maintaining/restoring riparian…
- Restoring channel form/function…
- Prescribed burns limit wildfire risks…
- Non-native species control…
- Improve/impede fish passage…

Where to do them?

Is there a grand strategy?

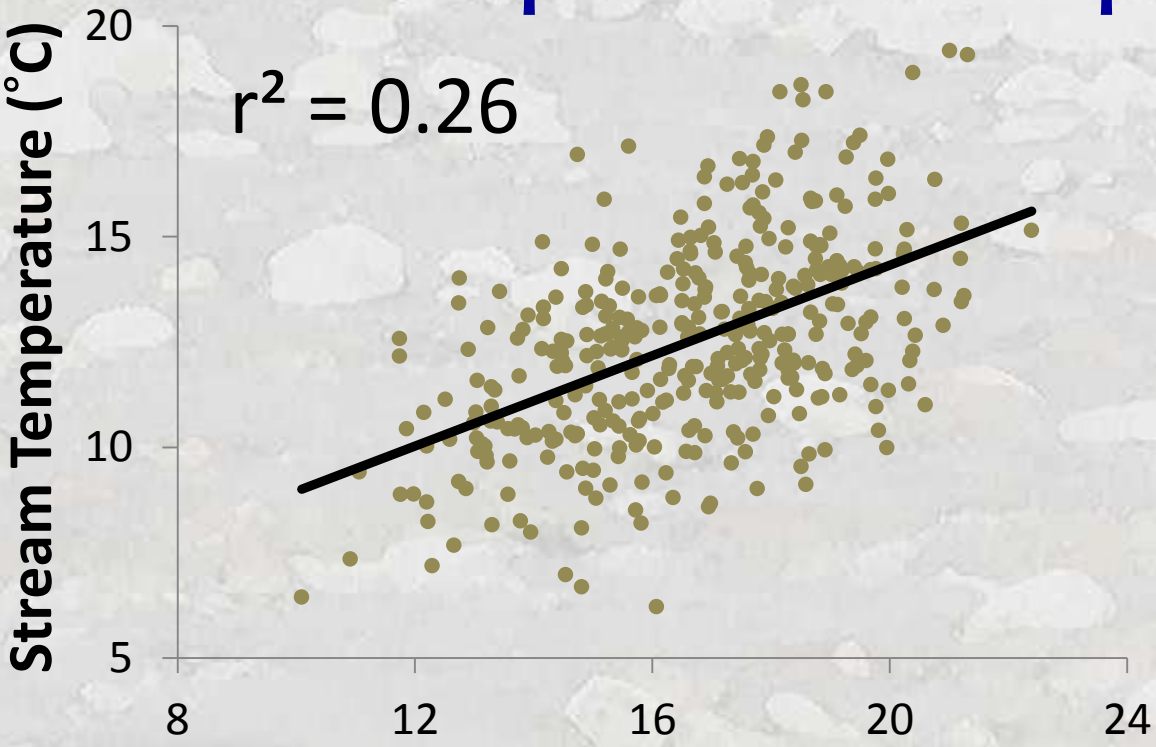
Many Climate Models & Scenarios for Air Temperature & Precipitation Exist…

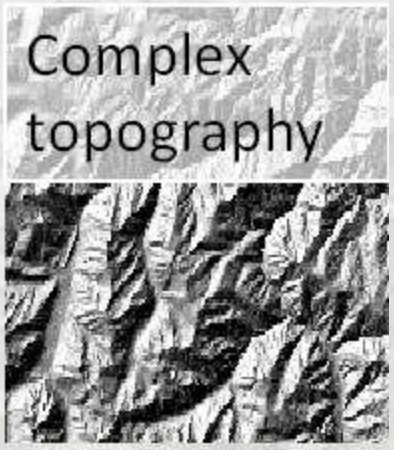


Mote & Salathe 2010

…but None for Stream Temperature

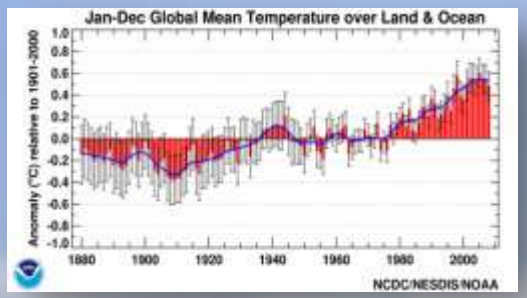
Air Temp ≠ Stream Temp





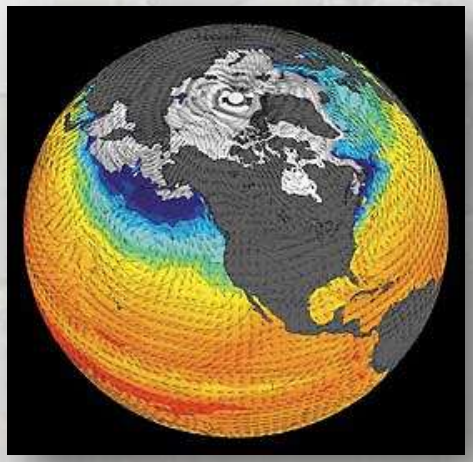
A Need for Regional Stream Scenarios

Taking Climate into the Water Where Fish Live…



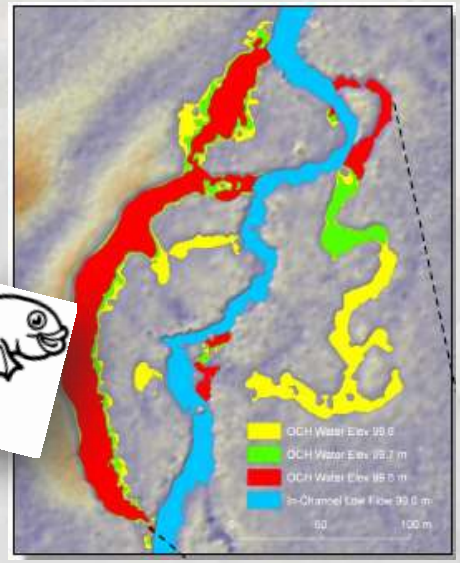
A Need for Regional Stream Scenarios

Climate model (air temp & precip)

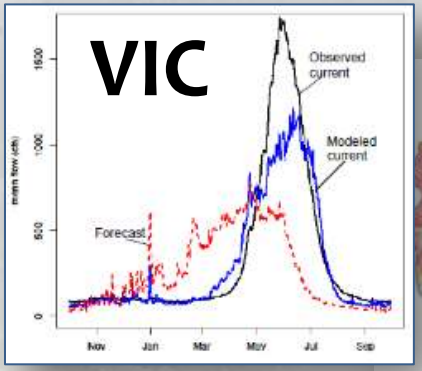


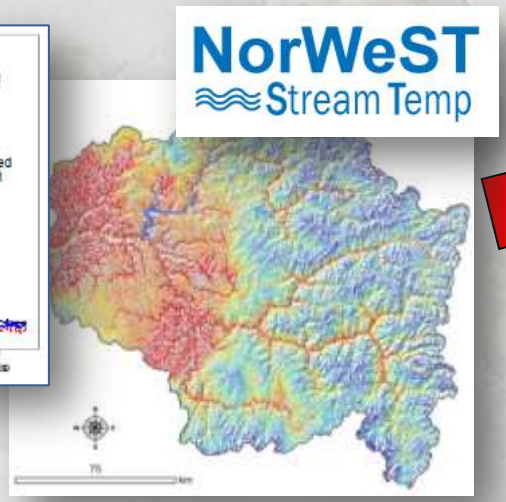
Regional patterns

Stream reach



Stream temperature & flow

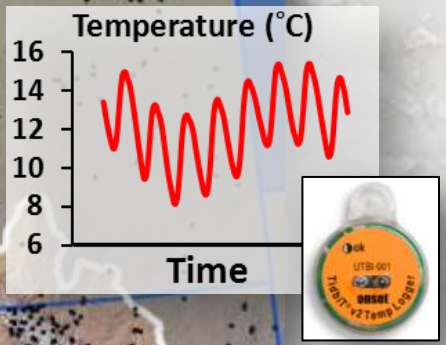




Lots of Data Exist…

NorWeST Stream Temp

>50,000,000 hourly records
>15,000 unique stream sites
>80 resource agencies



$10,000,000

WA
OR
CA
ID
NV
WY
UT

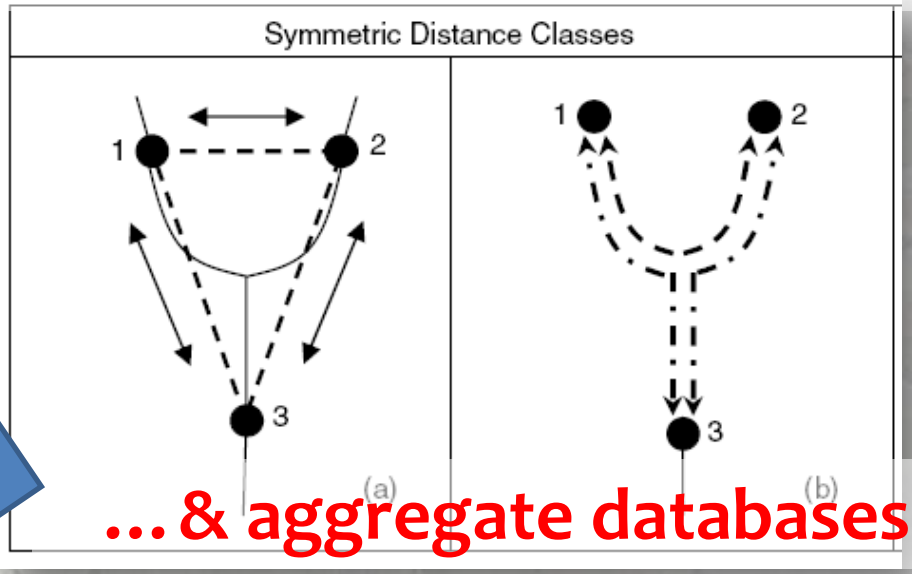
OREGON Fish & Wildlife
NOAA Fisheries
USGS science for a changing world
IDAHO POWER.

BIG DATA are often Autocorrelated

Spatial Statistical Network Models

Let's us connect the dots…

Valid interpolation on networks



… & aggregate databases

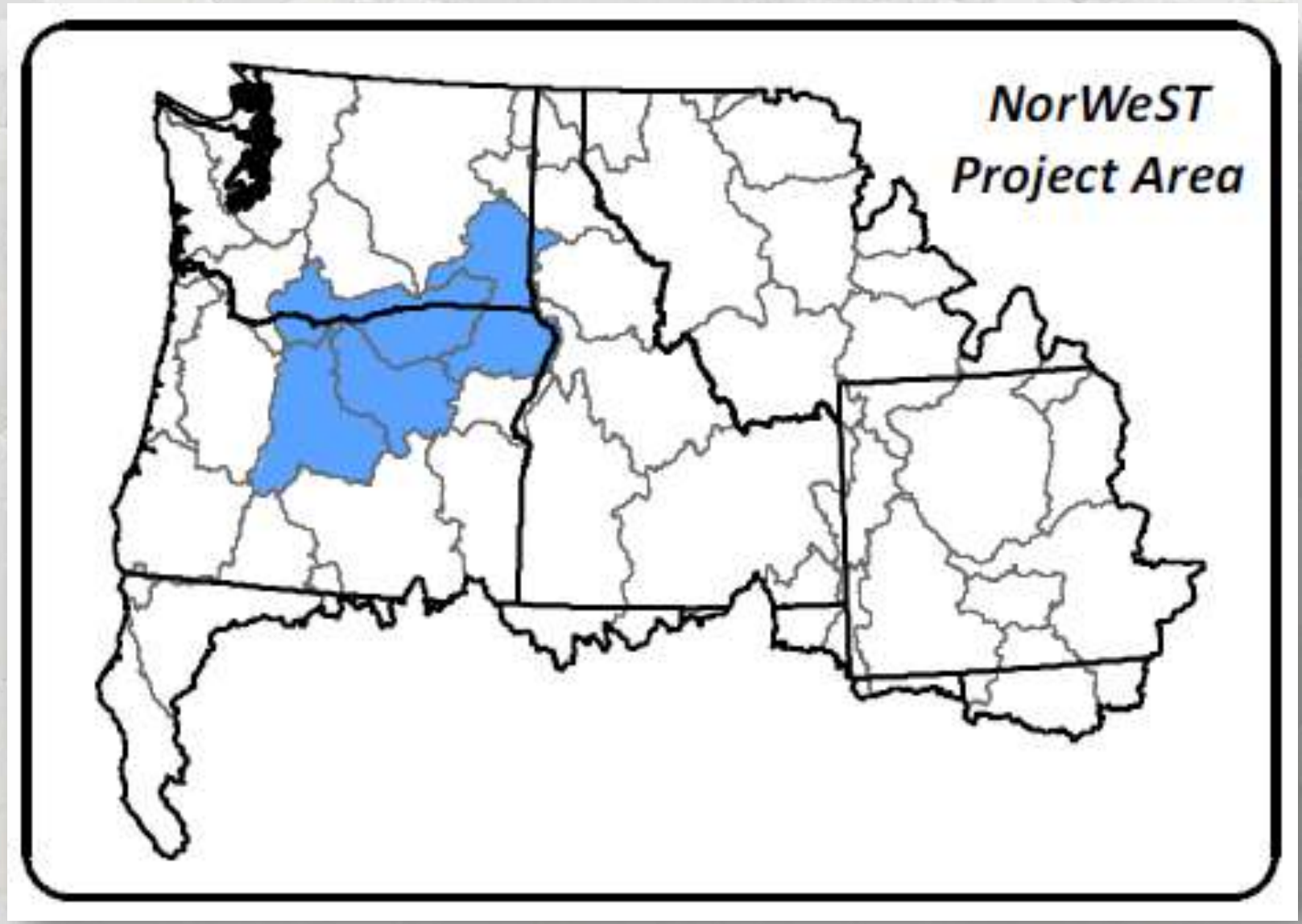
Advantages:

-flexible & valid autocovariance structures that accommodate network topology & non-independence among observations

-improved predictive ability & parameter estimates relative to non-spatial models

Ver Hoef et al. 2006; Ver Hoef & Peterson 2010; Peterson & Ver Hoef 2013

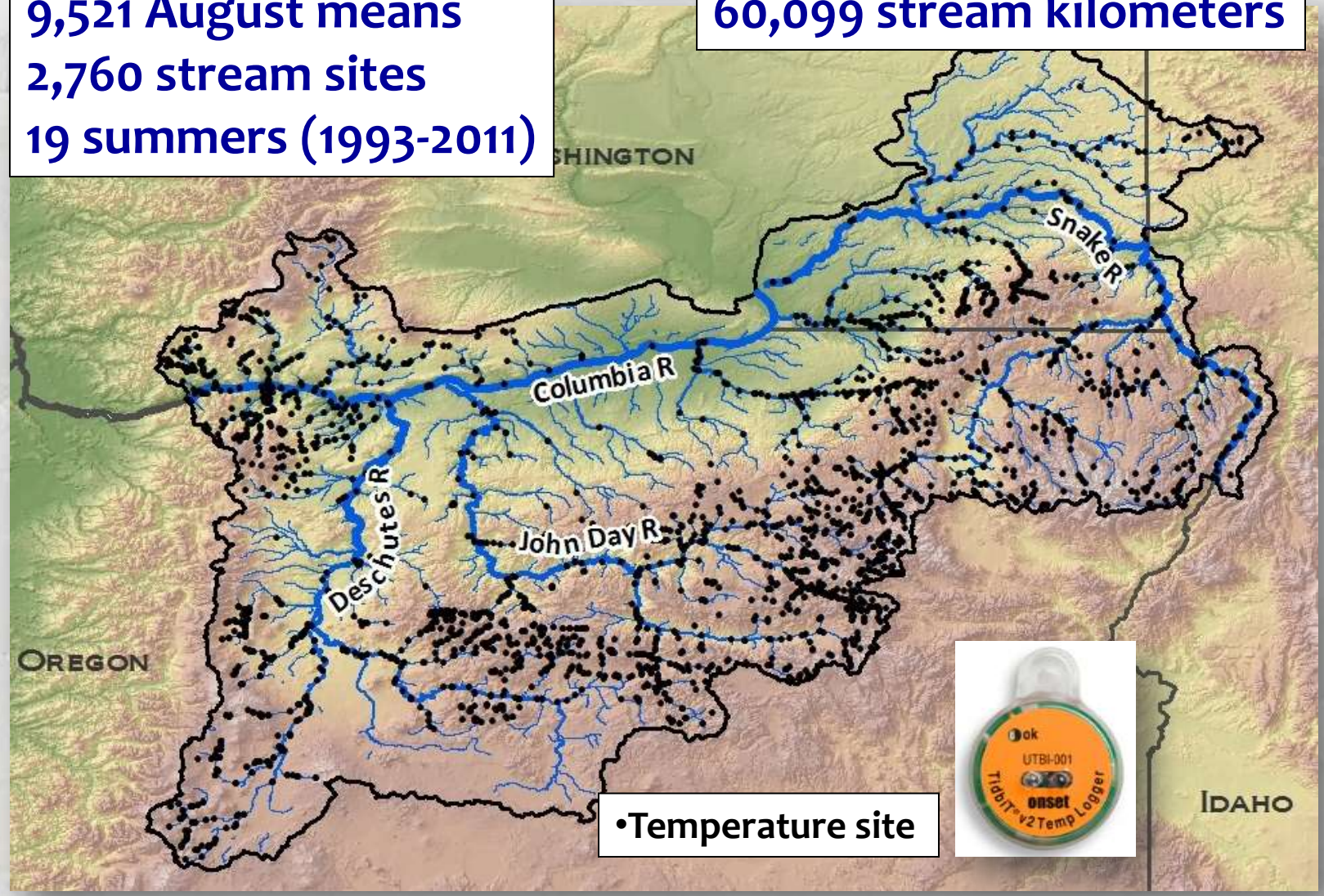
NorWeST Temperature Model for the Mid-Columbia



NorWeST Temperature Model for the Mid-Columbia

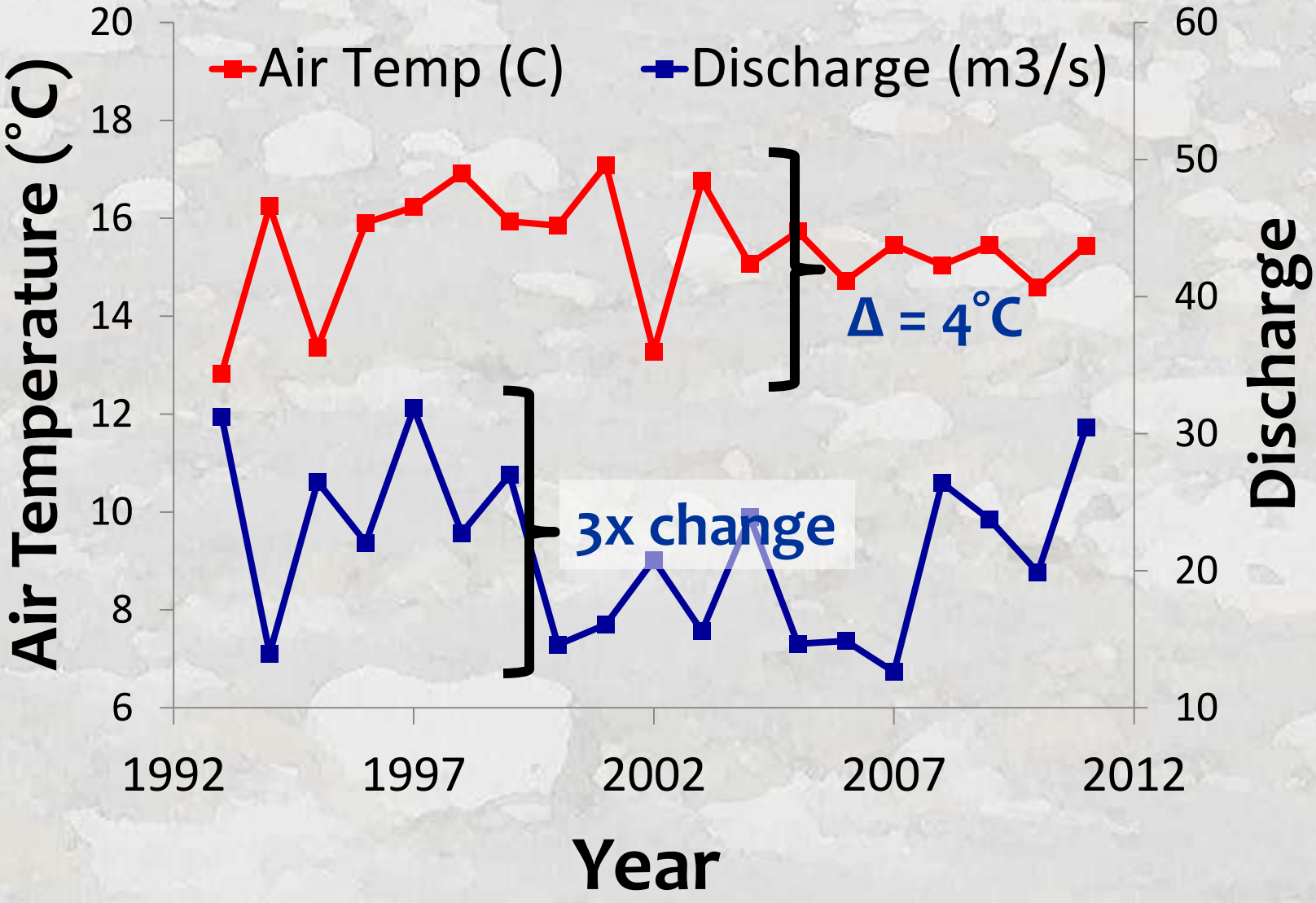
9,521 August means
2,760 stream sites
19 summers (1993-2011)

60,099 stream kilometers



Climatic Variability in Historical Record

Extreme years encompass mid-Century averages



Mid-Columbia Temperature Model

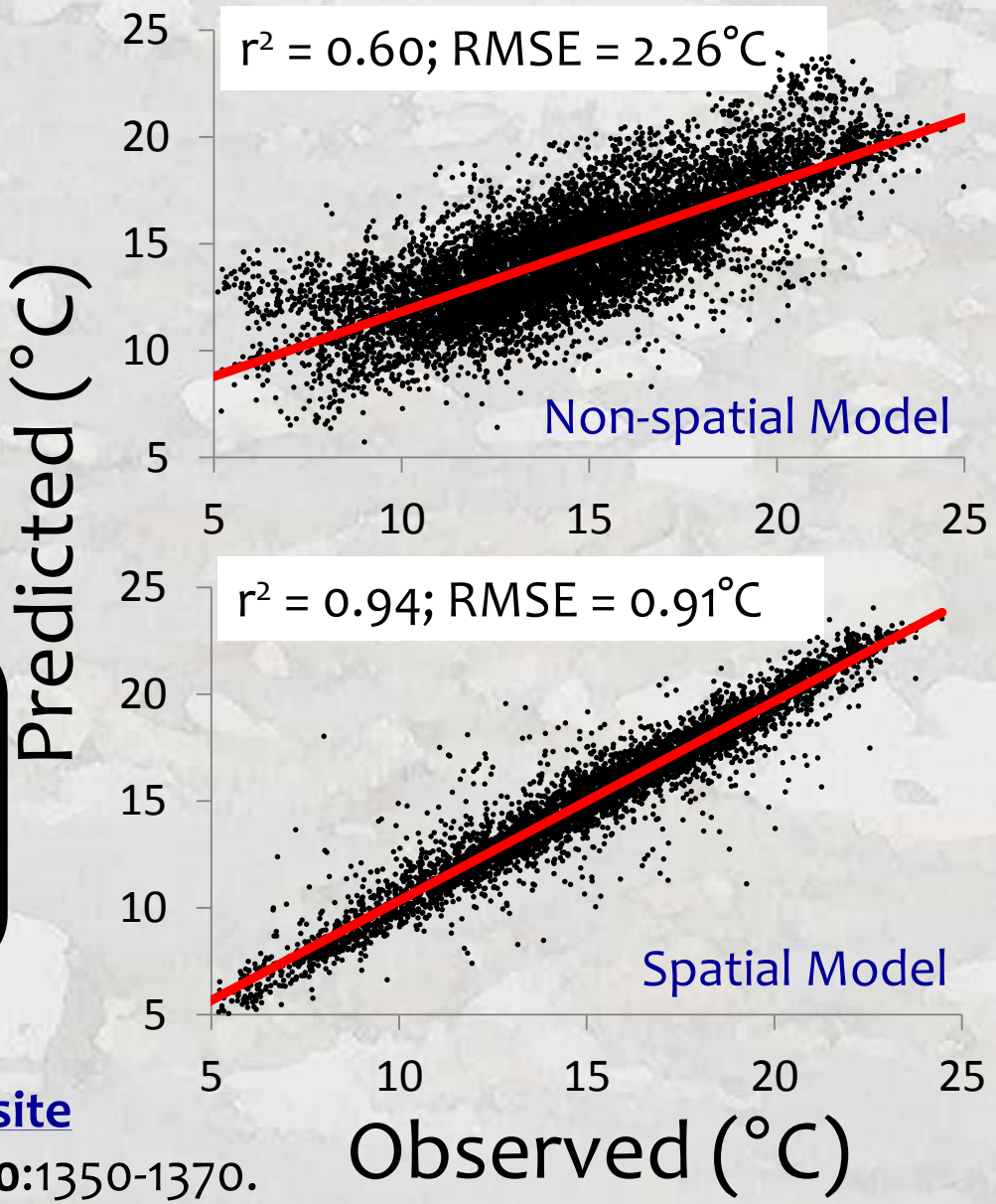
n = 9,521

Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km^2)
9. Glacier (%)

10. Discharge (m^3/s)
    USGS gage data
11. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature



More details: **NorWeST website**

Isaak et al. 2010. *Ecol. Apps* **20**:1350-1370.

"Means" vs Short-Term Maxima…

- Short-term metrics are difficult to model
  - More variable/less stable than means
  - Occur @ different times each year (GCM linkage)
- Summer metrics are strongly correlated

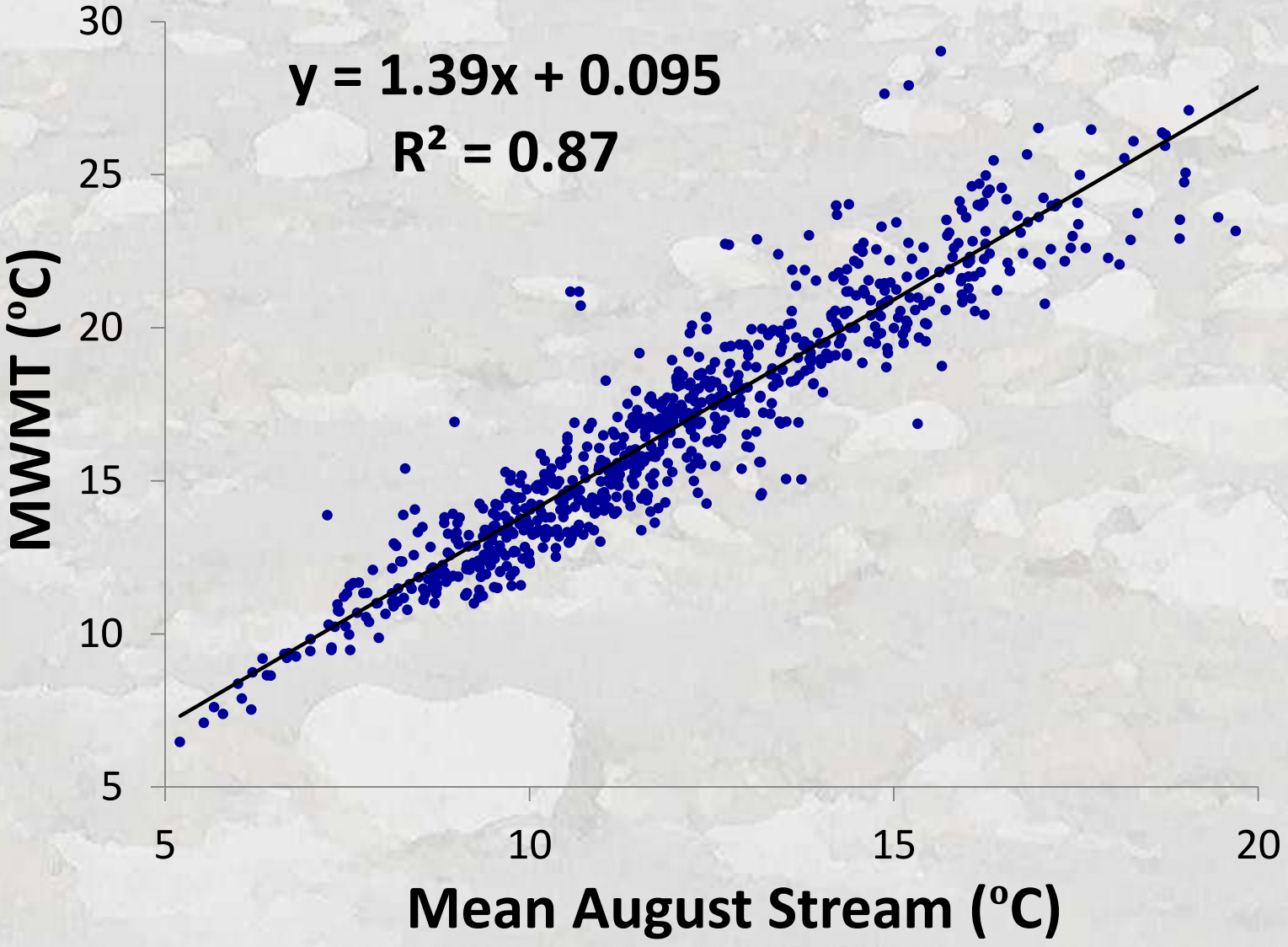
MWAT ~ **Maximum** ~ **Minimum**

MDAT ~ **AWAT** ~ **Degree-days** ~ Mean

	Summer_mn	*Mwmt*	*Mwat*	*awat_mn*	*awmt_mn*	***August Mean***
Summer_mn						
Mwmt	0.93					
Mwat	0.98	0.94				
awat_mn	1.00	0.93	0.97			
awmt_mn	0.96	0.98	0.94	0.96		
August Mean	**0.99**	**0.92**	**0.96**	**0.99**	**0.95**	
August MWMT	0.92	0.99	0.92	0.92	0.98	**0.92**

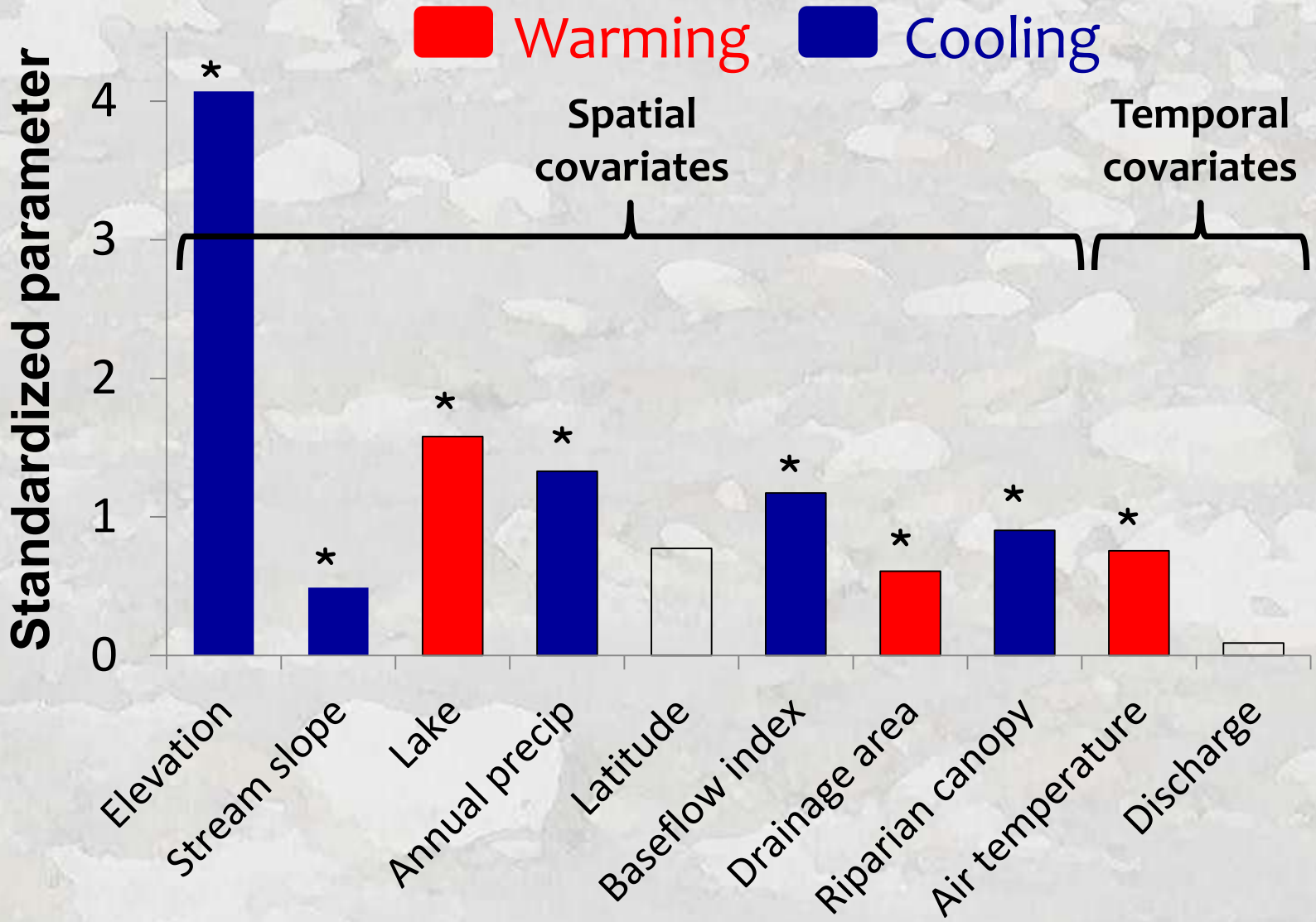
It's the Same "Information"

So Metric Conversions are Easy…



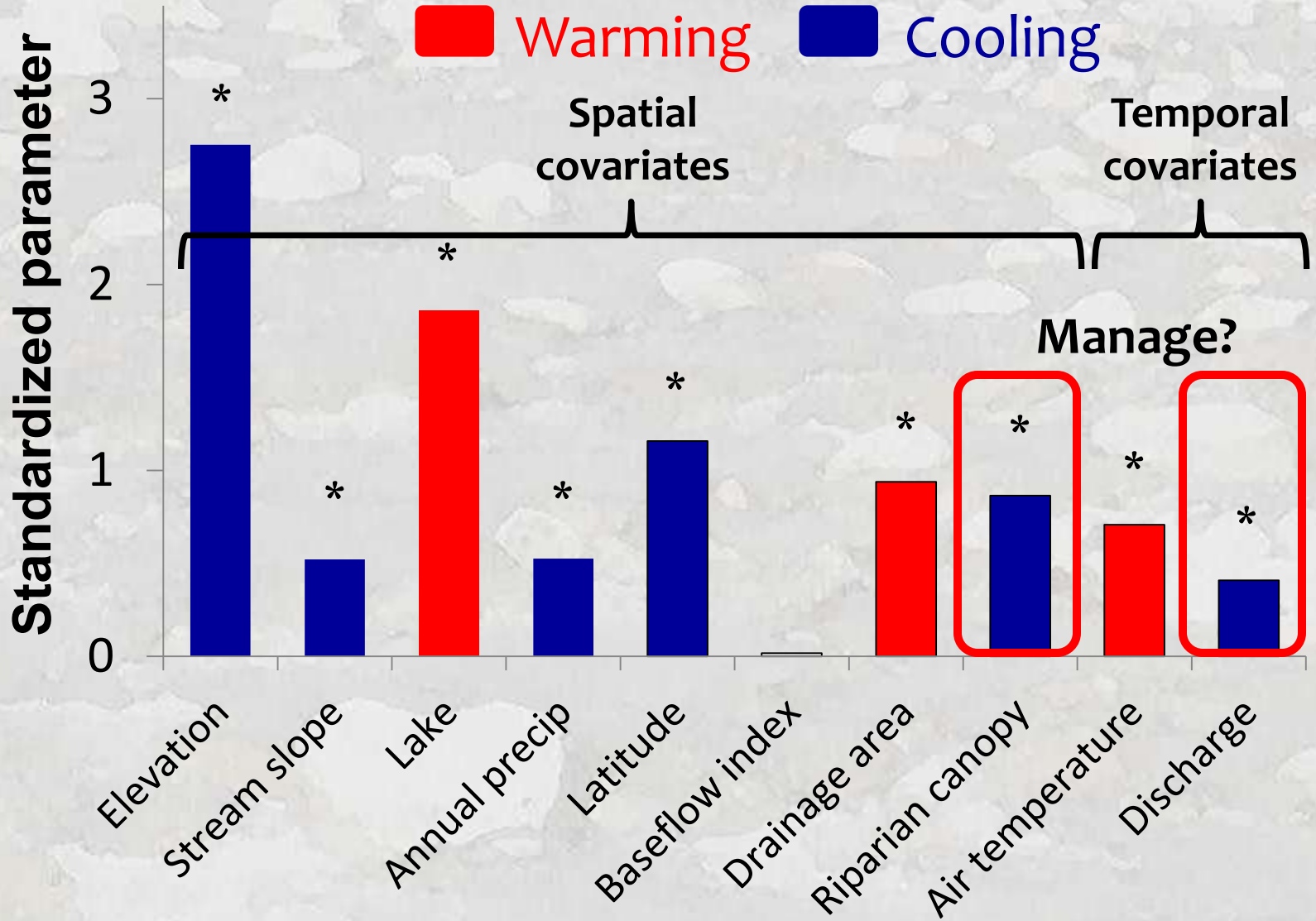
Relative Effects of Predictors

Mid-Columbia River Basin Model



Relative Effects of Predictors

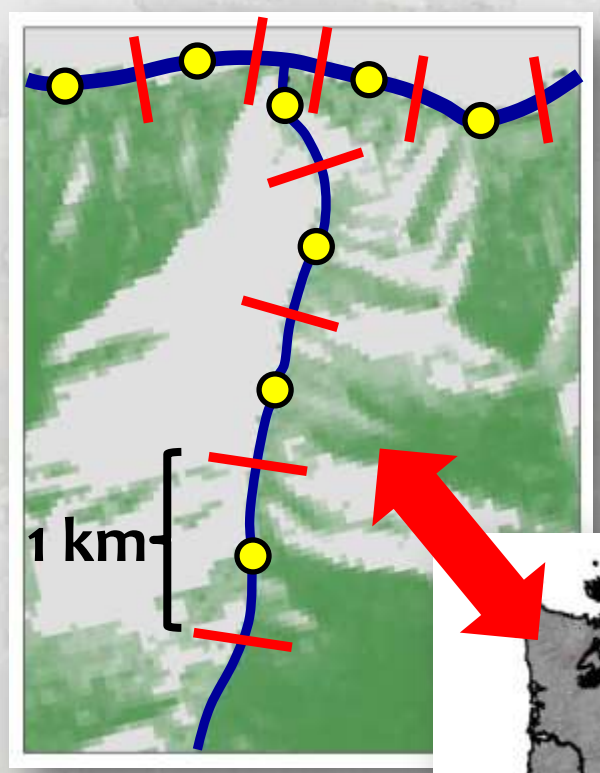
Northwest Montana Model

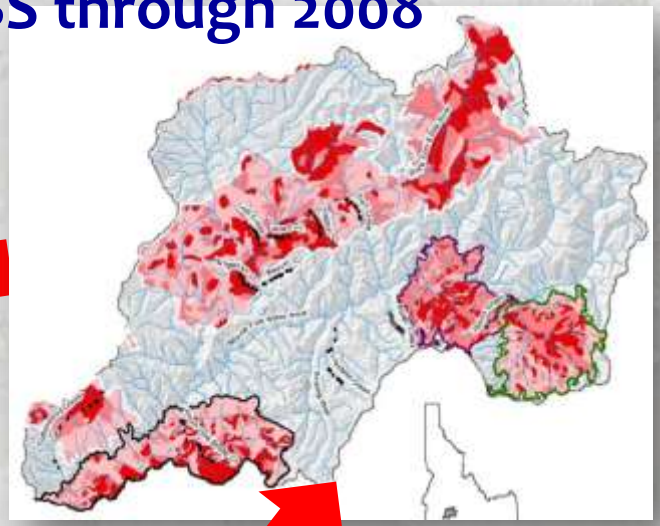


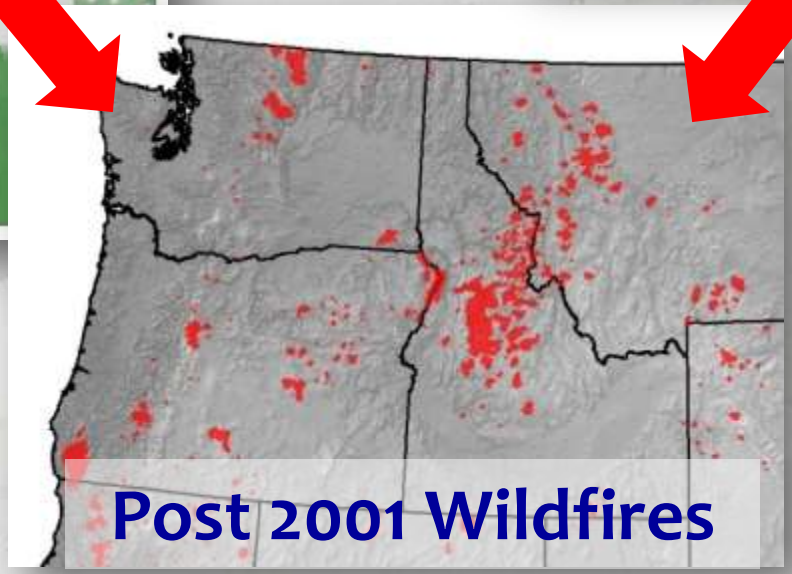
Riparian Canopy Predictor

%Canopy variable from 2001 NLCD

%Canopy adjusted by MTBS through 2008



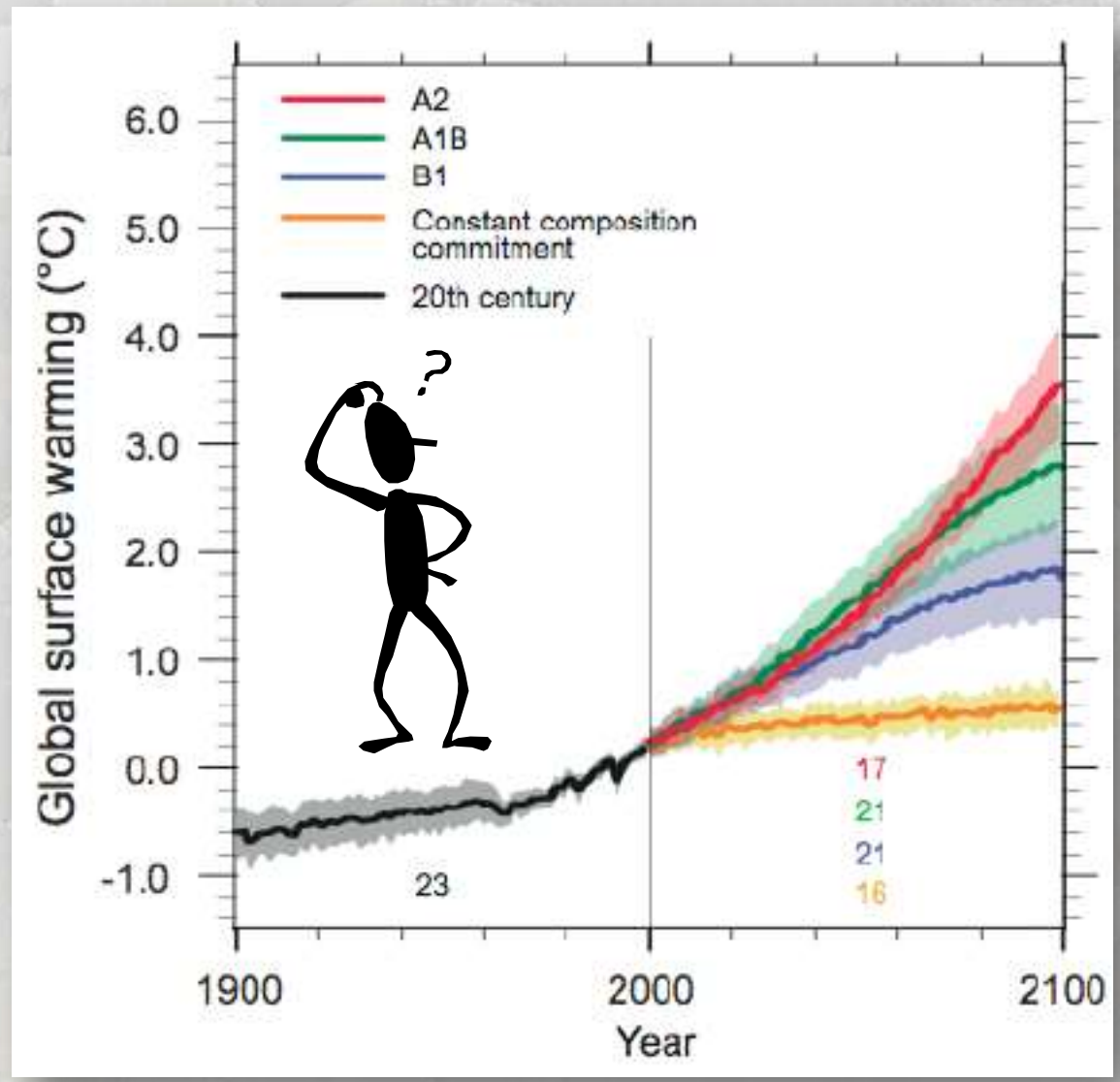




Post 2001 Wildfires

Models Enable Climate Scenario Maps

Many possibilities exist…



Adjust…

- **Air**
- **Discharge**
- **%Canopy**

…values to create scenarios

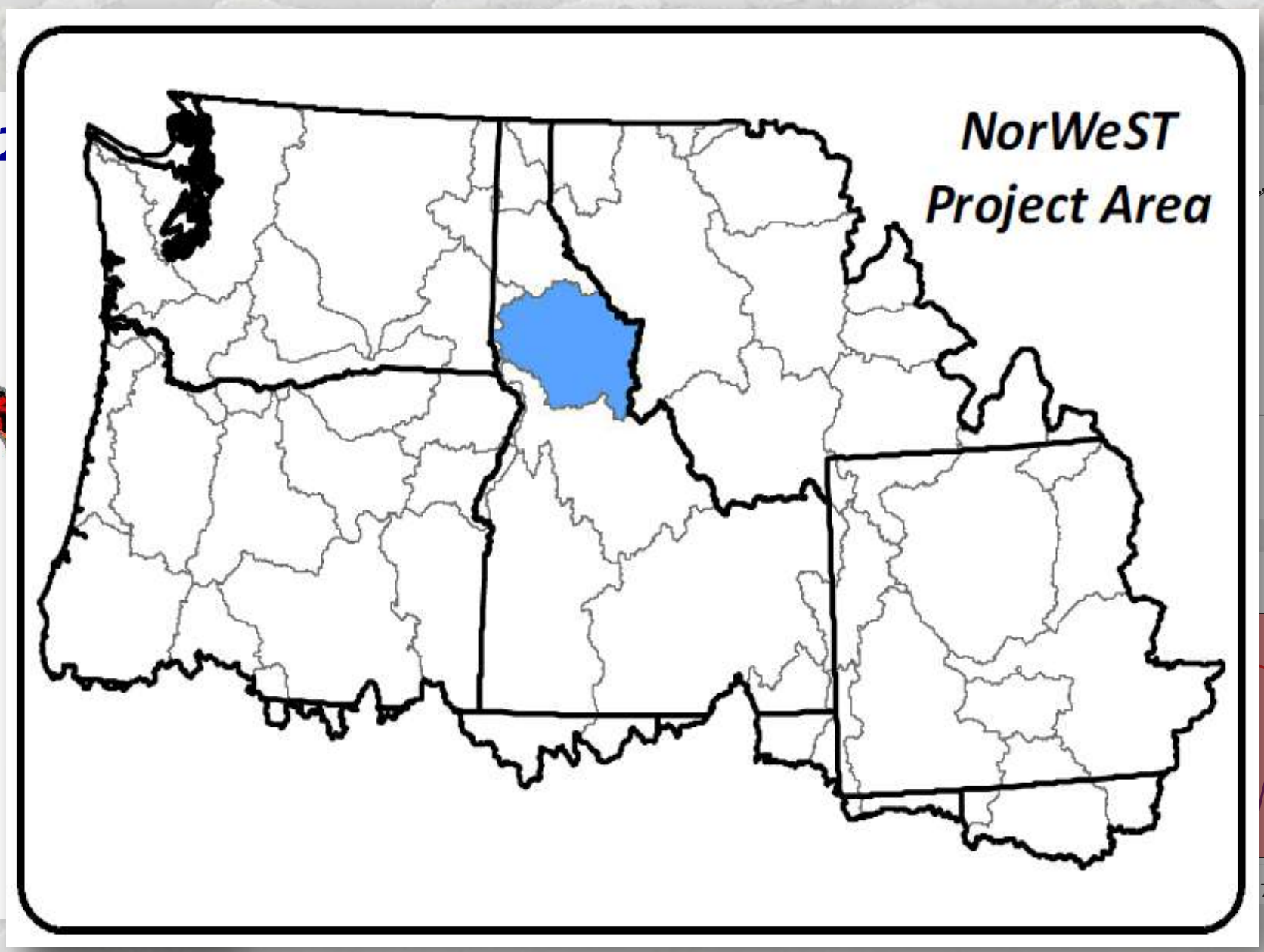
NorWeST Historical Scenarios

Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures for 1993
S4_1994	Historical scenario representing August mean stream temperatures for 1994
Etc…	
S21_2011	Historical scenario representing August mean stream temperatures for 2011

***2012 & 2013 starting with Washington**

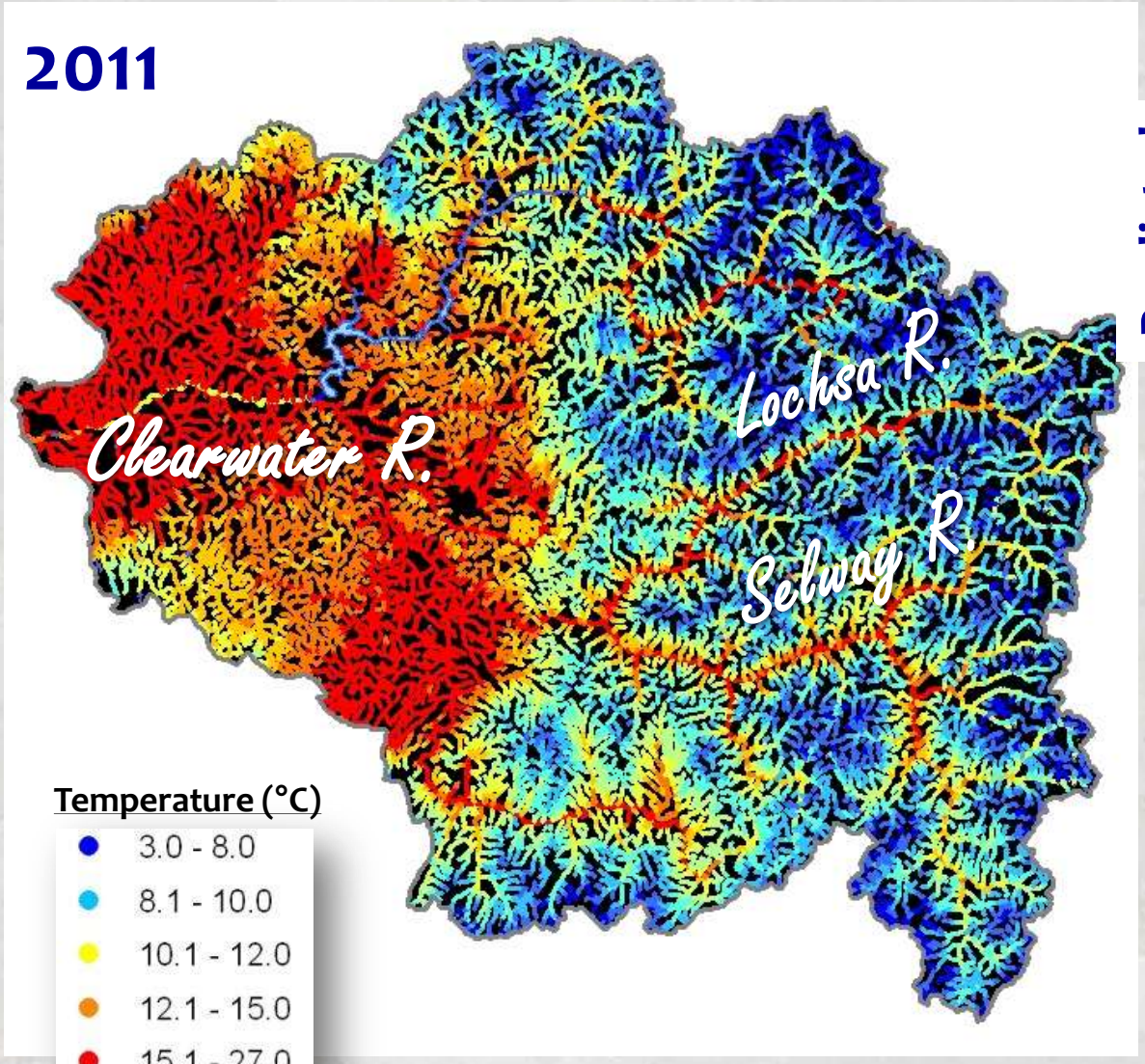
***Extensive metadata on website**

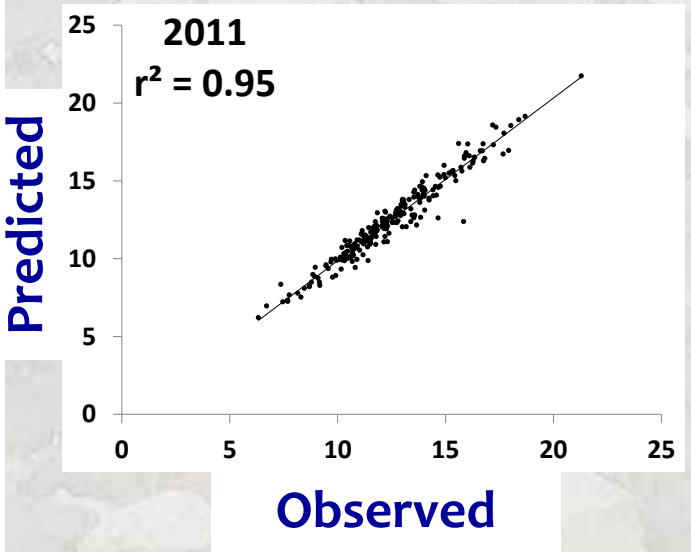
Historical Year Sequence (1993-2011)

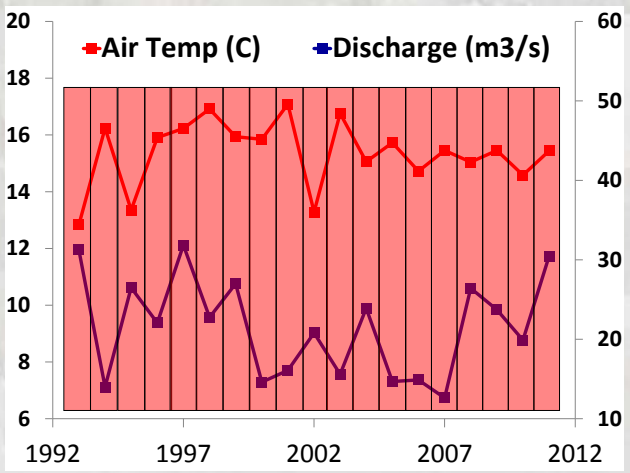


Historical Year Sequence (1993-2011)

Mean August Temperature - Clearwater Basin

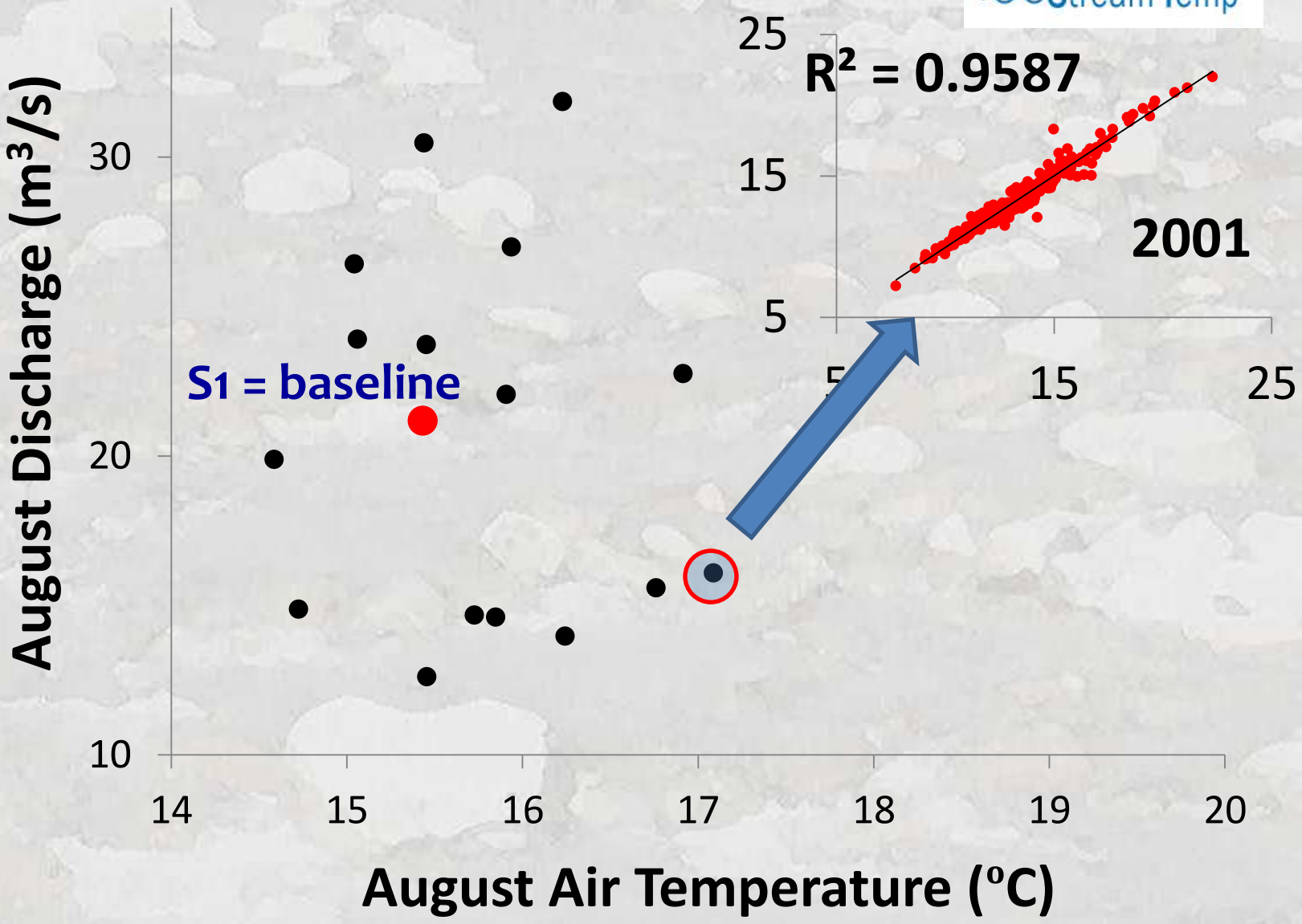






Climate Envelope Model Assessment

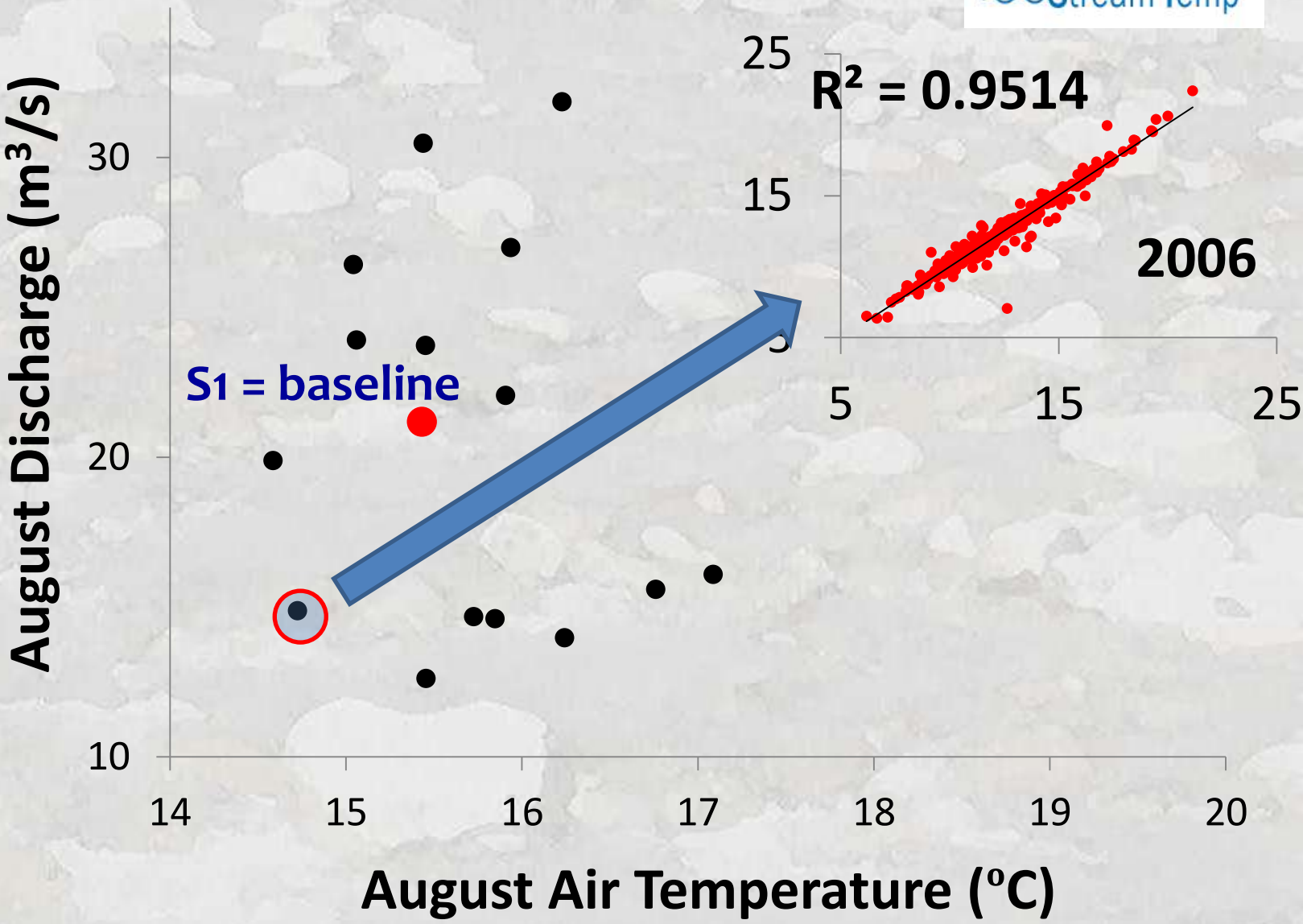
Clearwater Basin (1993-2011)



Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

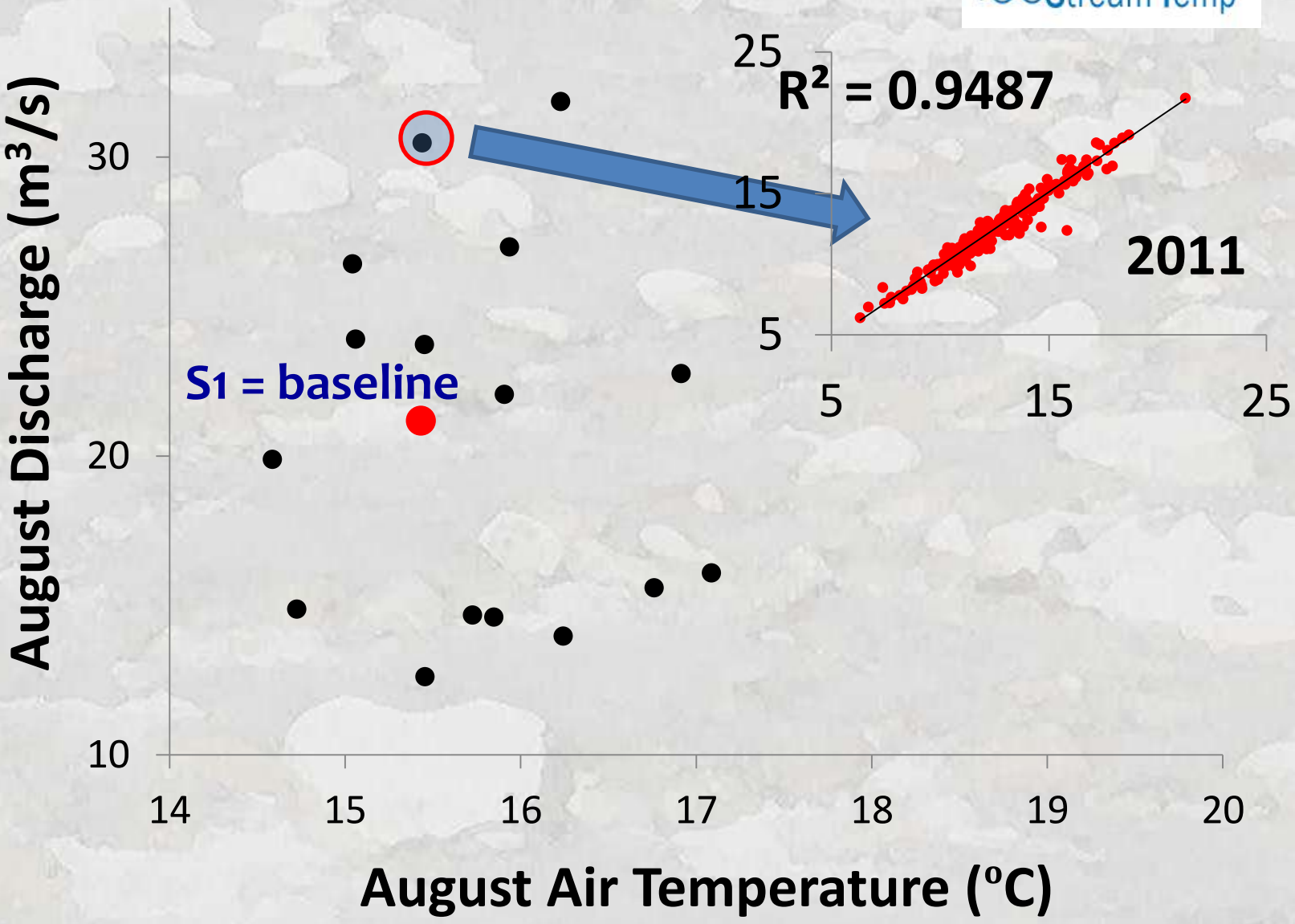
NorWeST Stream Temp



Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

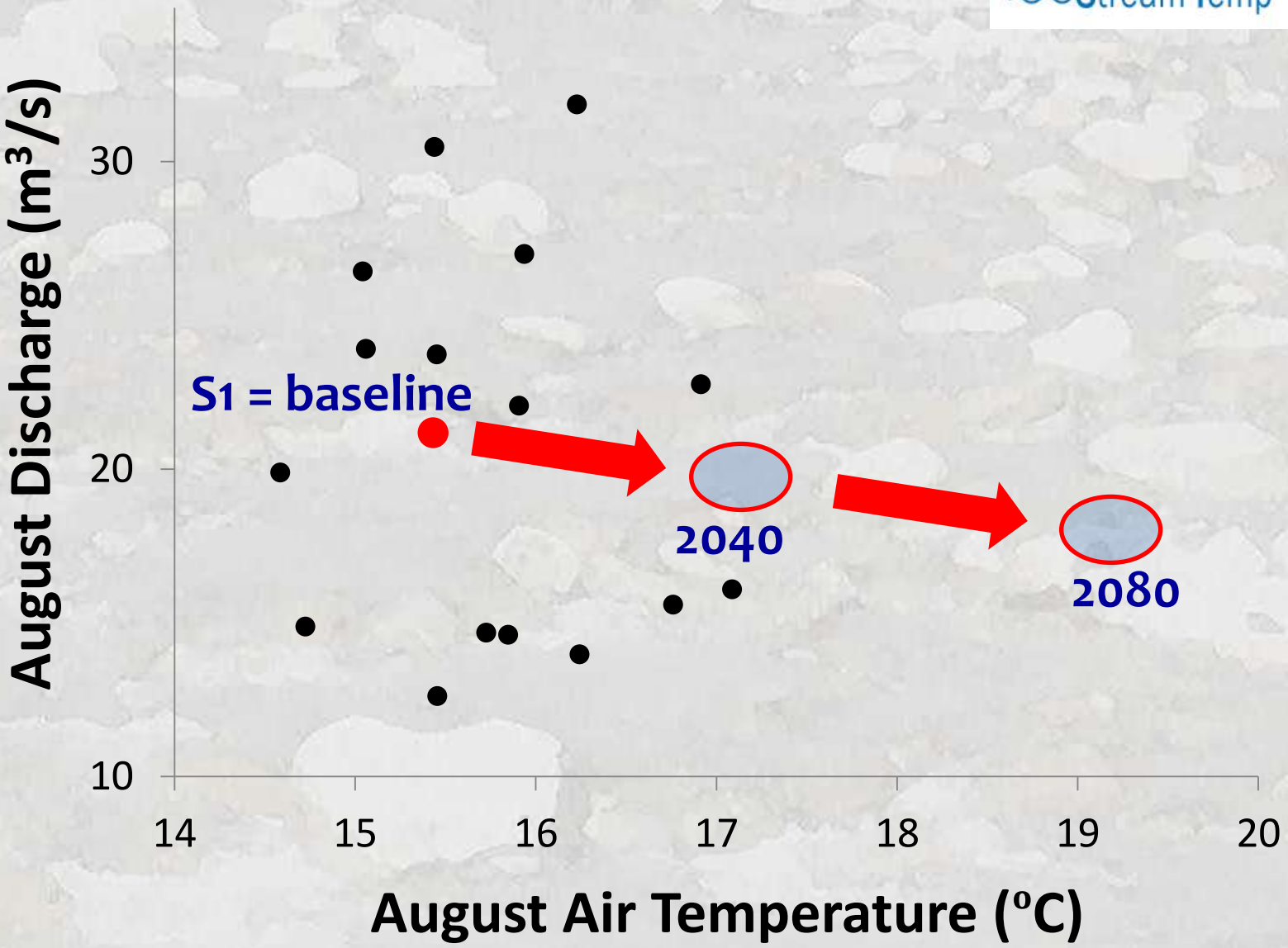
NorWeST Stream Temp



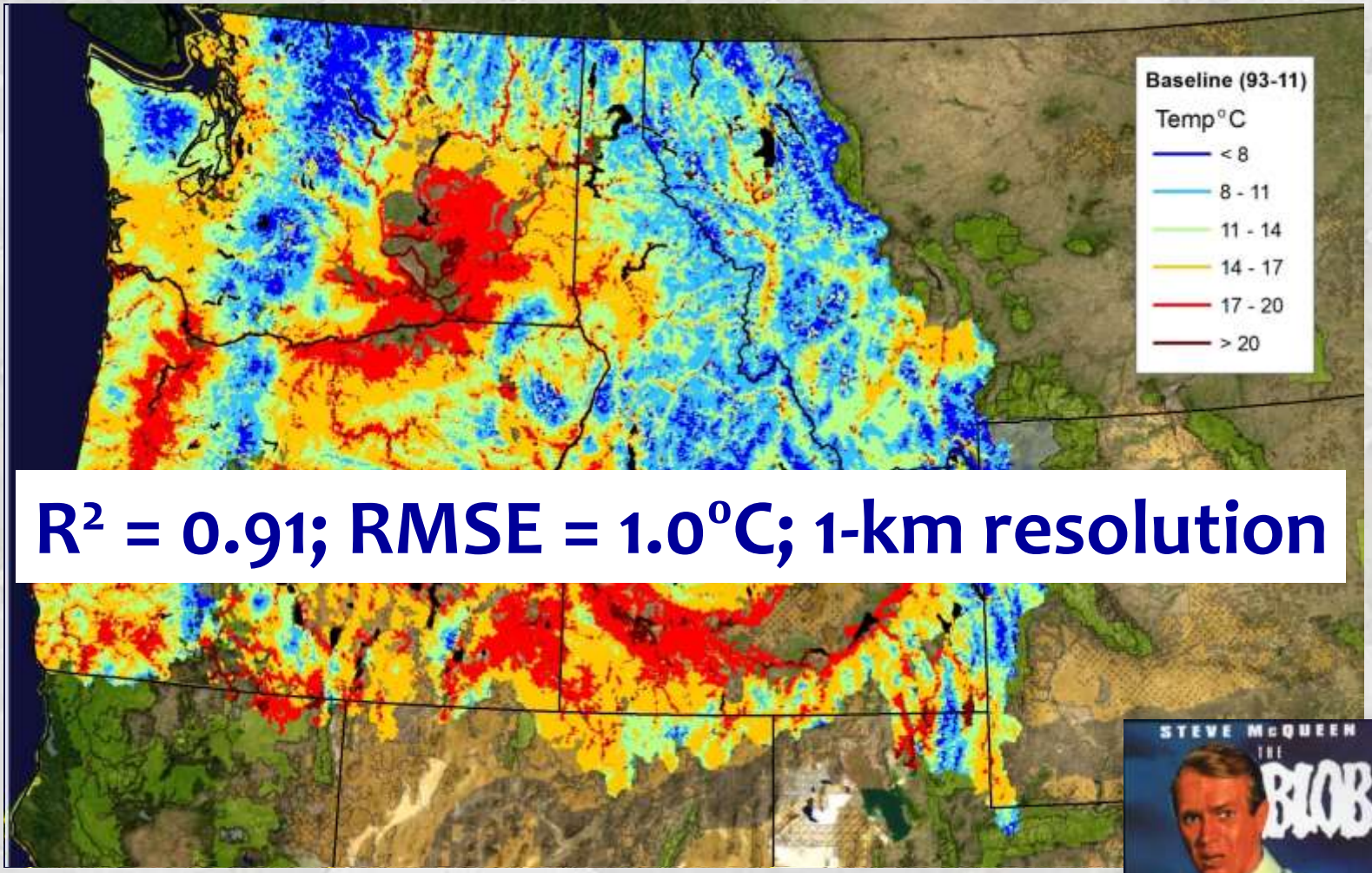
Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

NorWeST Stream Temp



High-Resolution Stream Temp Scenarios

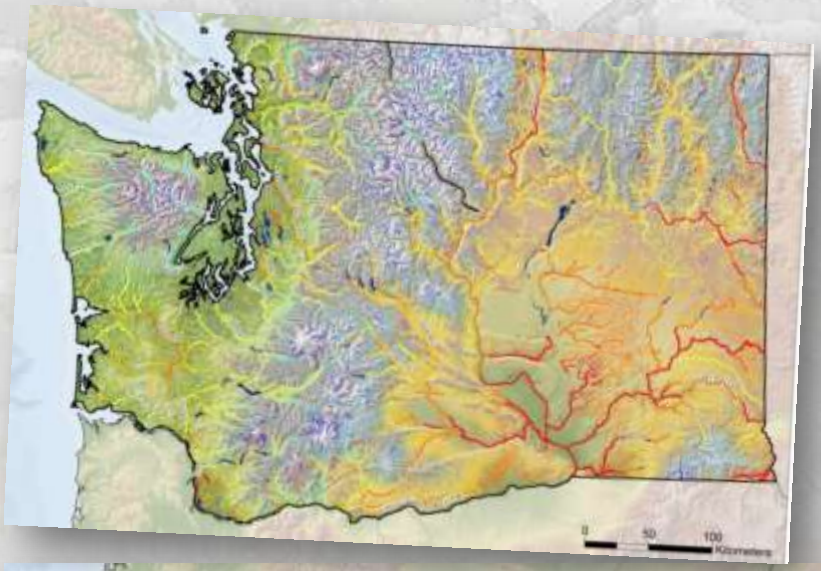


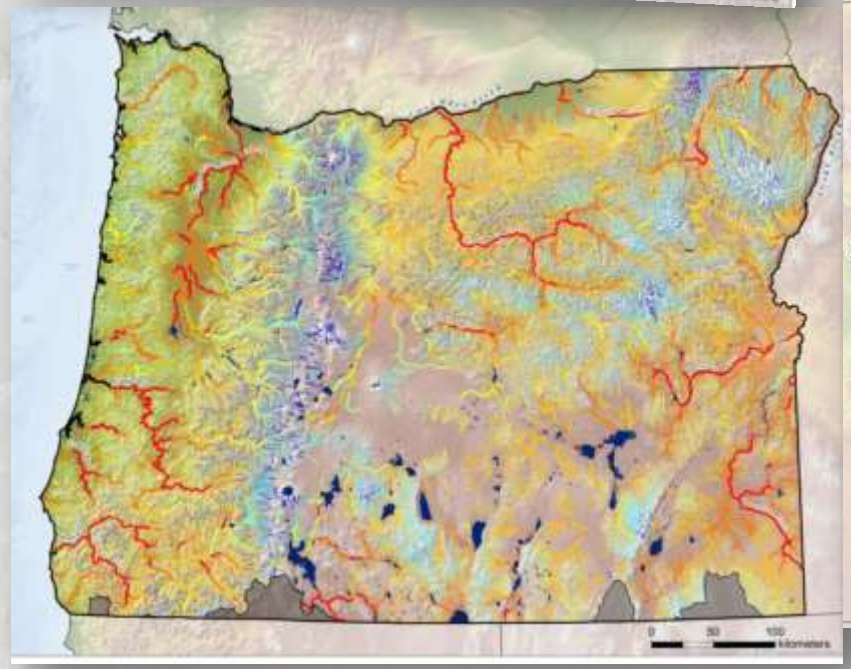
R^2 = 0.91; RMSE = 1.0°C; 1-km resolution

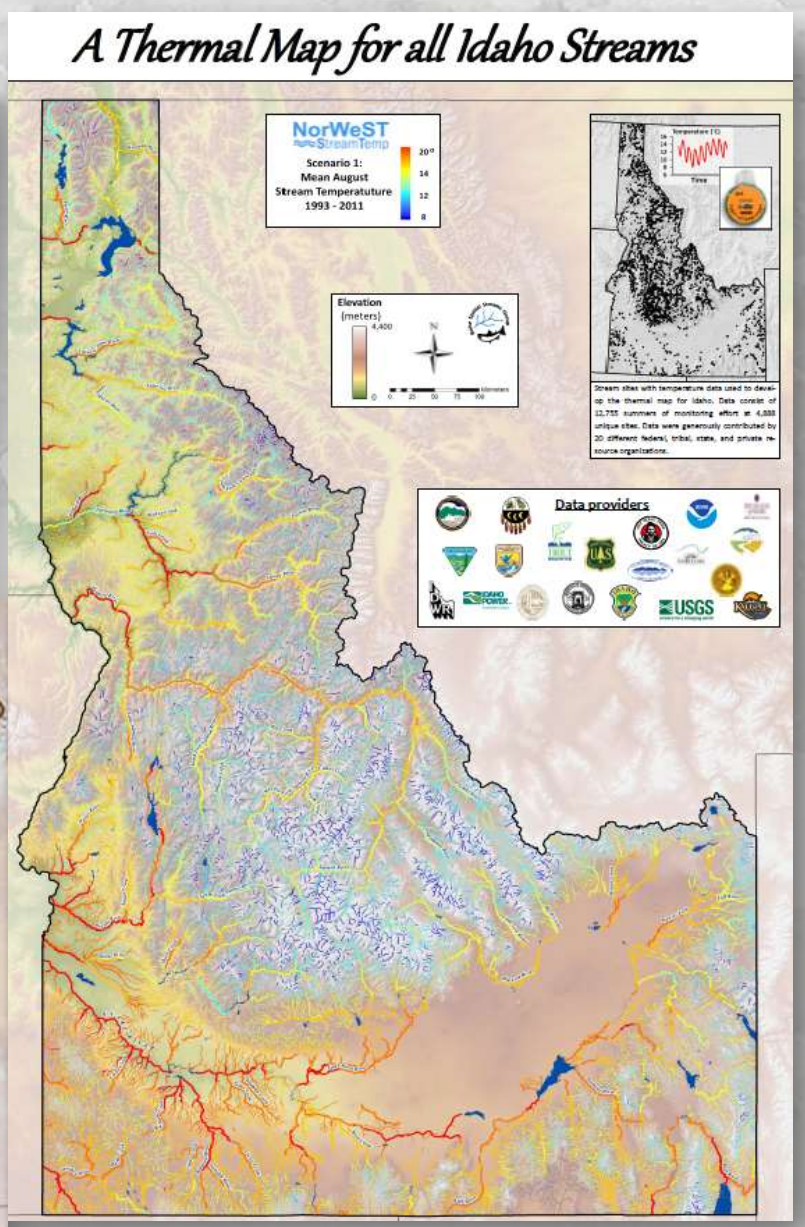
The BLOB… it just keeps growing…

- 46,674 summers of data swallowed
- 467,000 stream kilometers of thermal ooze

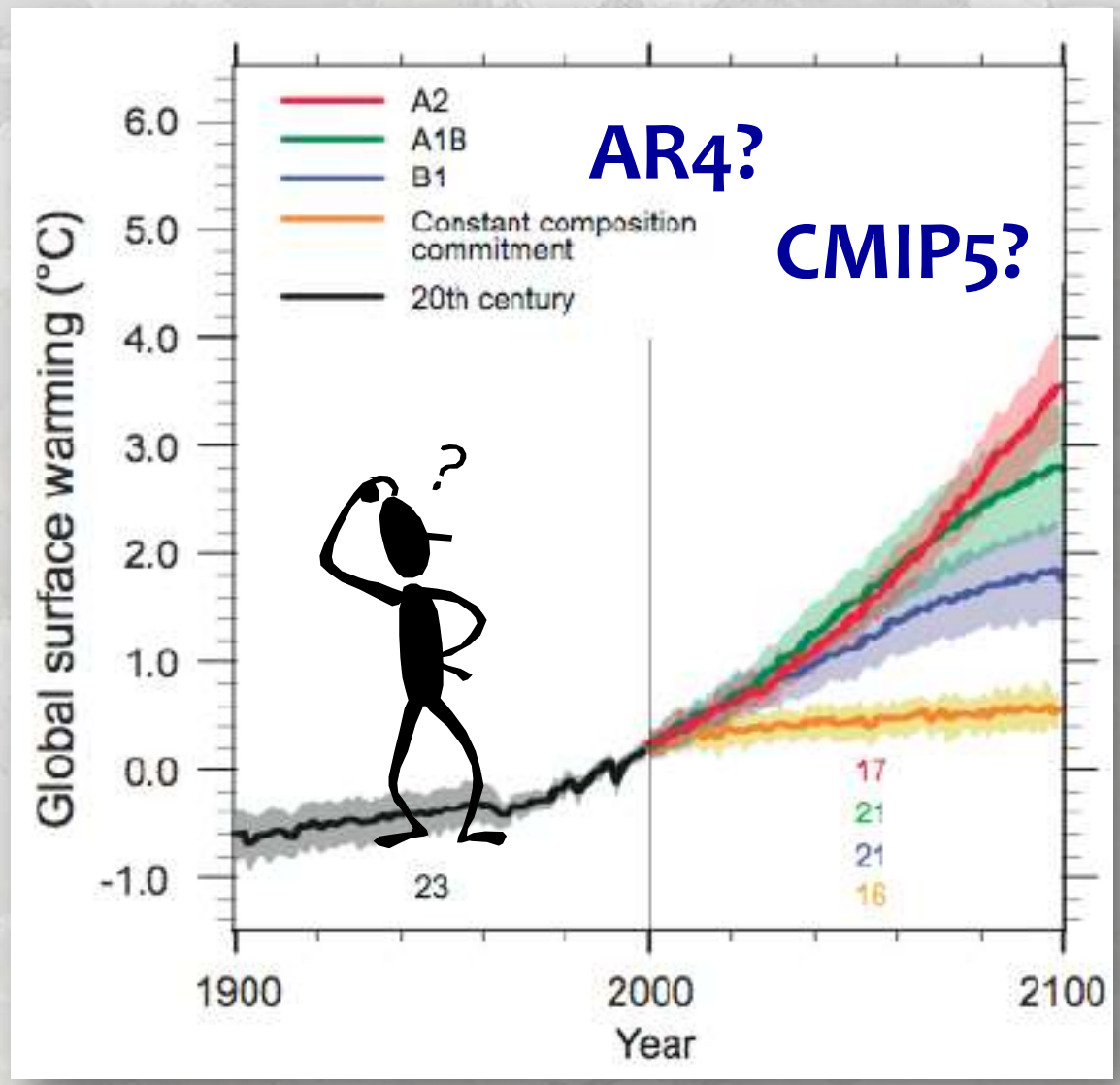
State Stream Temperature Maps…







Future Scenarios – Which to Choose?



The Specifics are an "Unknowable Unknown"

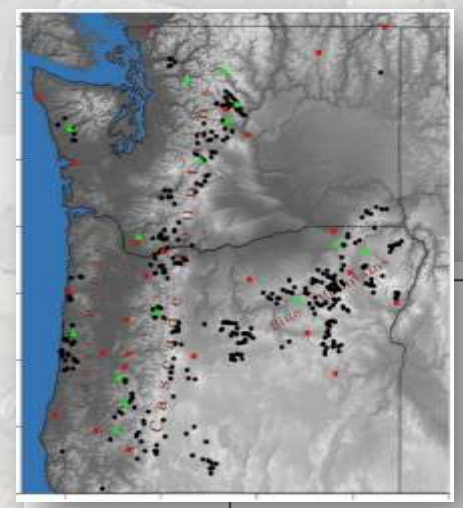
Just plan on it gradually getting warmer…

10 NorWeST Future Scenarios

Scenario	Description
S23_1C	Future scenario adds 1ºC to S1_93-11
S24_1C_D	Future scenario adds 1ºC to S1_93-11 & incorporates differential stream sensitivity
Etc…	For +2ºC & +3ºC
S29_2040	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble.
S30_2040_D	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble. Adjustment applied for differential sensitivity.
S31_2080	Etc…

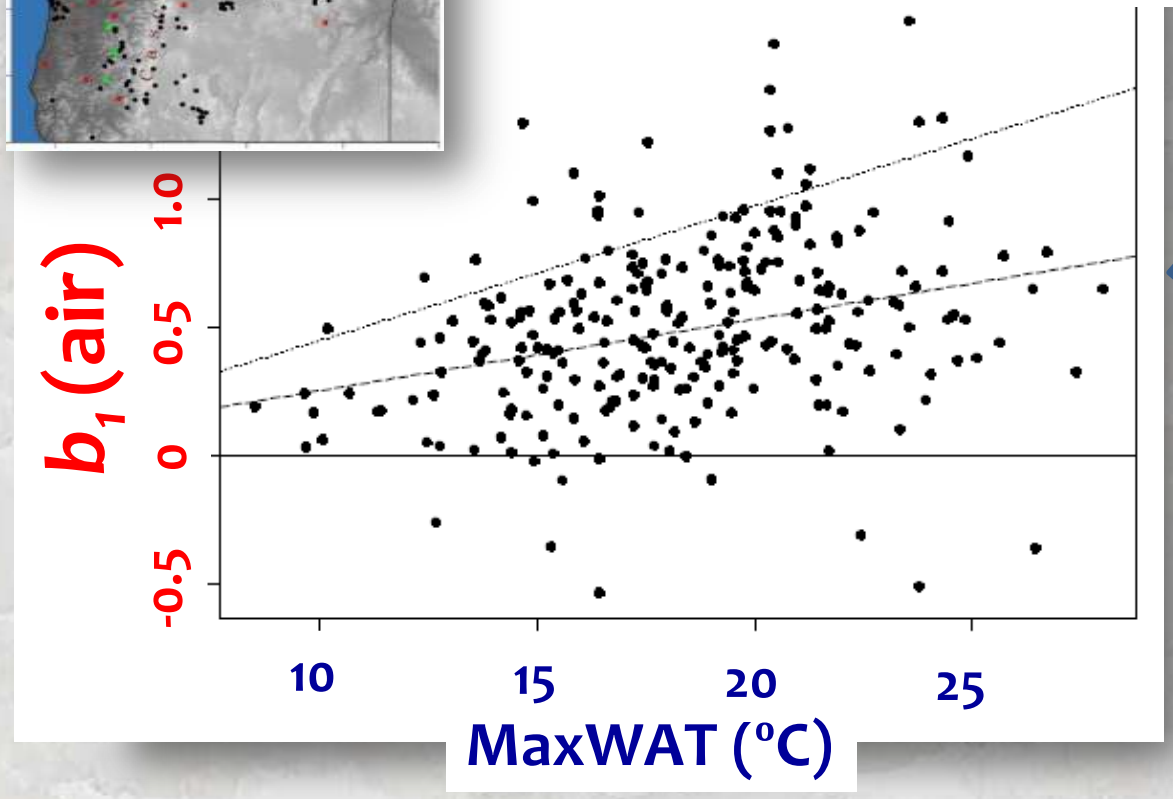
***Extensive metadata on website**

Cold Streams Less Sensitive to Climate Forcing



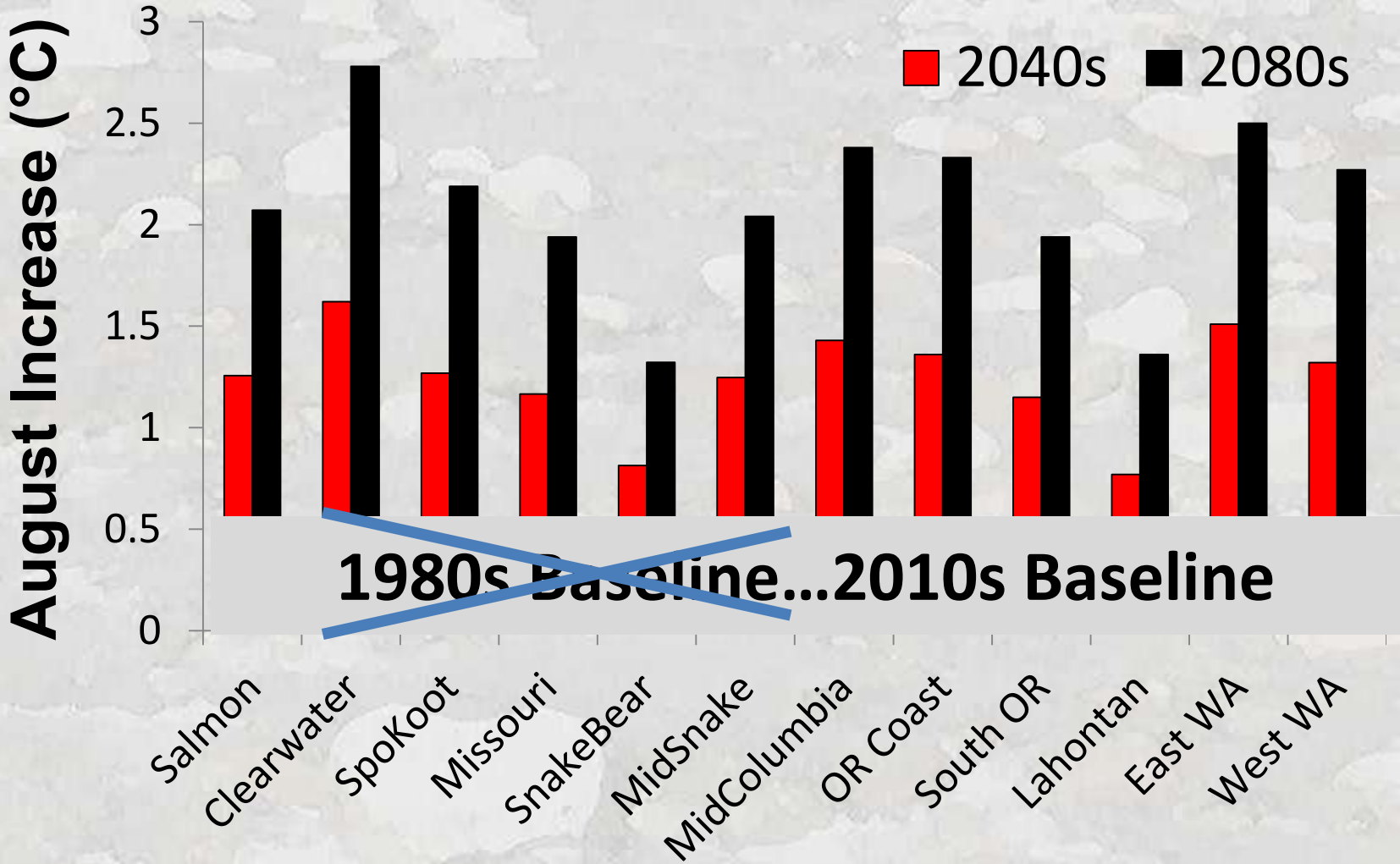
246 stream sites with >7 summers of data

MaxWAT = b_1(air) + b_2(discharge)



Luce et al. 2014. Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. Water Resources Research 50: 1-16.

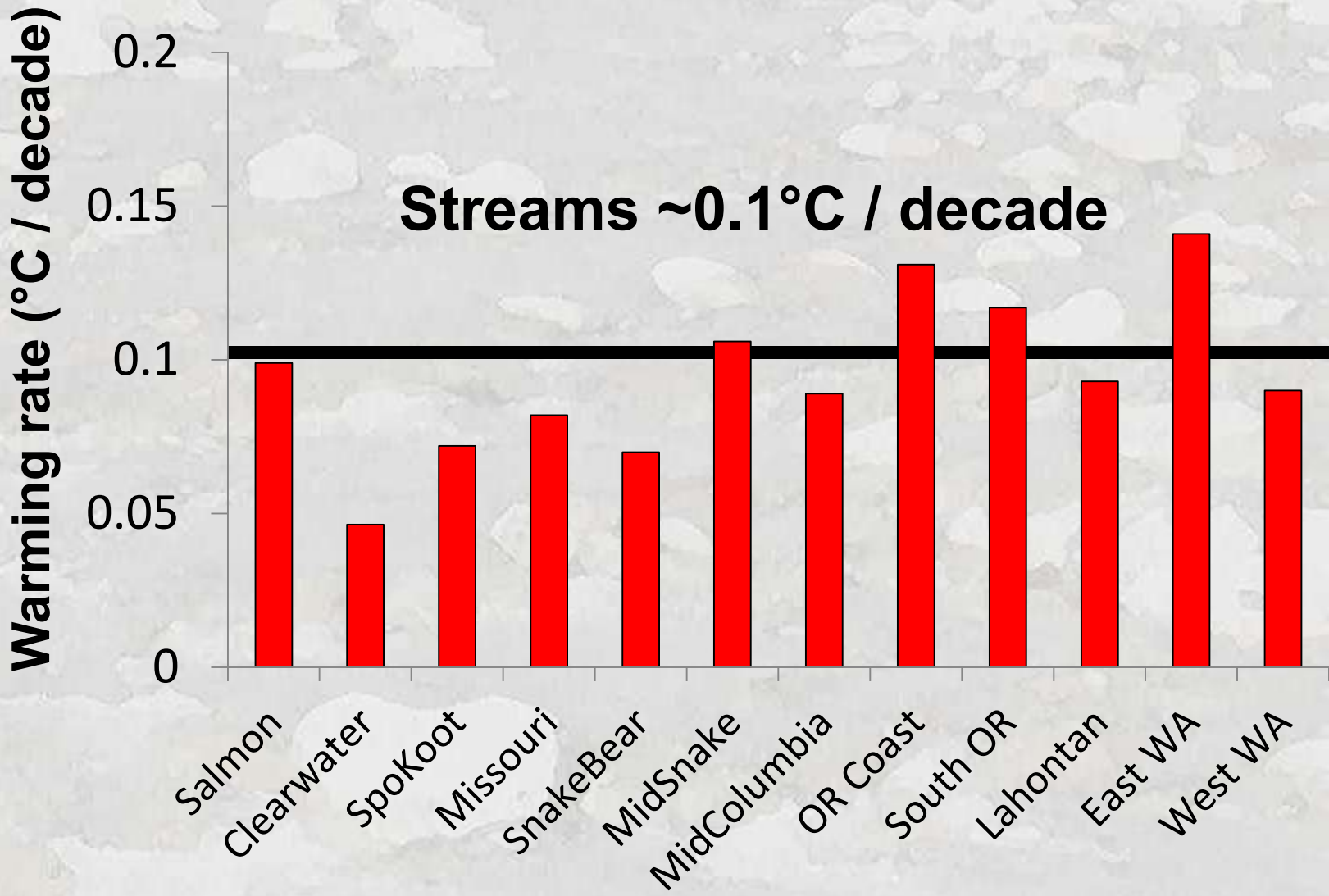
Future Increases Relative to 1980s (1970-1999) Baseline: CIG 10 GCM ensemble for A1B trajectory



*Variation within basins +/-50% from sensitivity adjustment

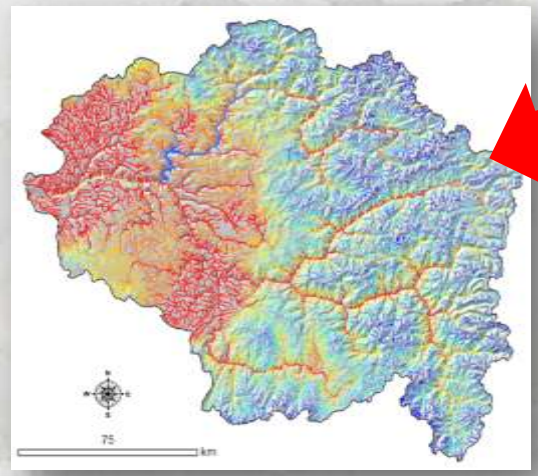
Reality Check: Past August Warming Rates

Reconstructions for 44 Year Period (1968 – 2011)

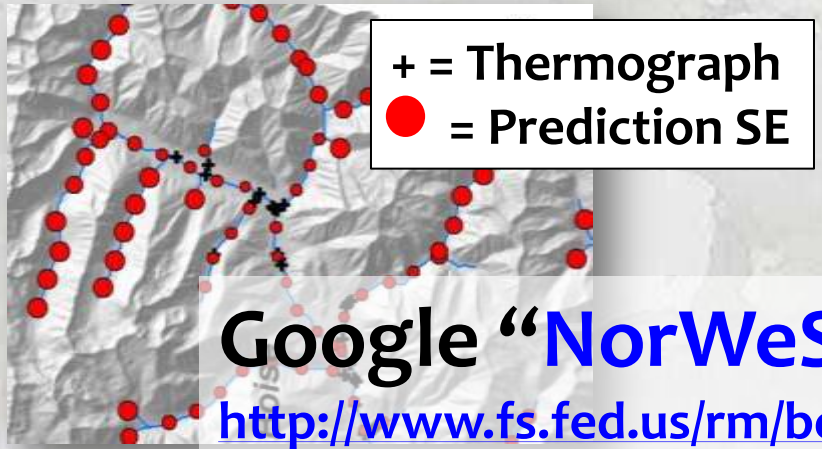


Website Distributes BLOB Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision



3) Temperature data summaries

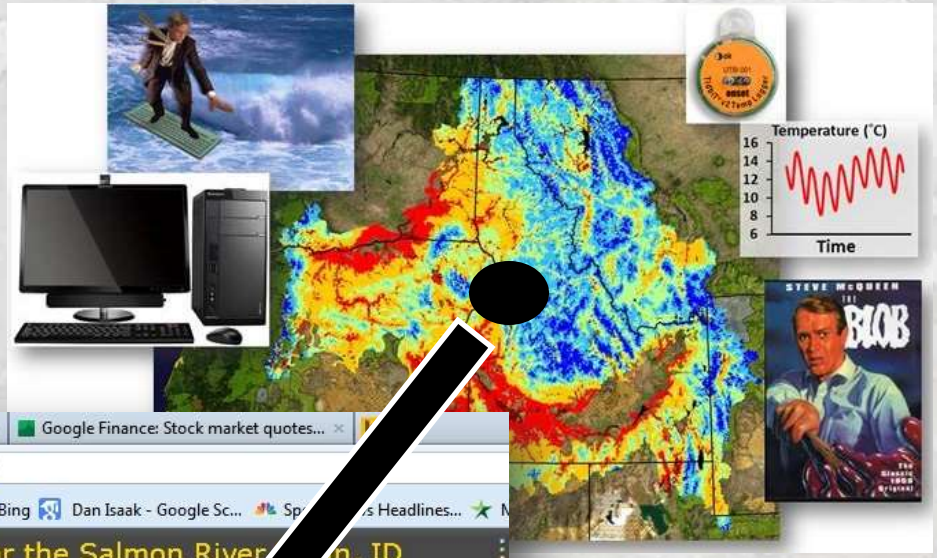
Google "NorWeST" or go here…

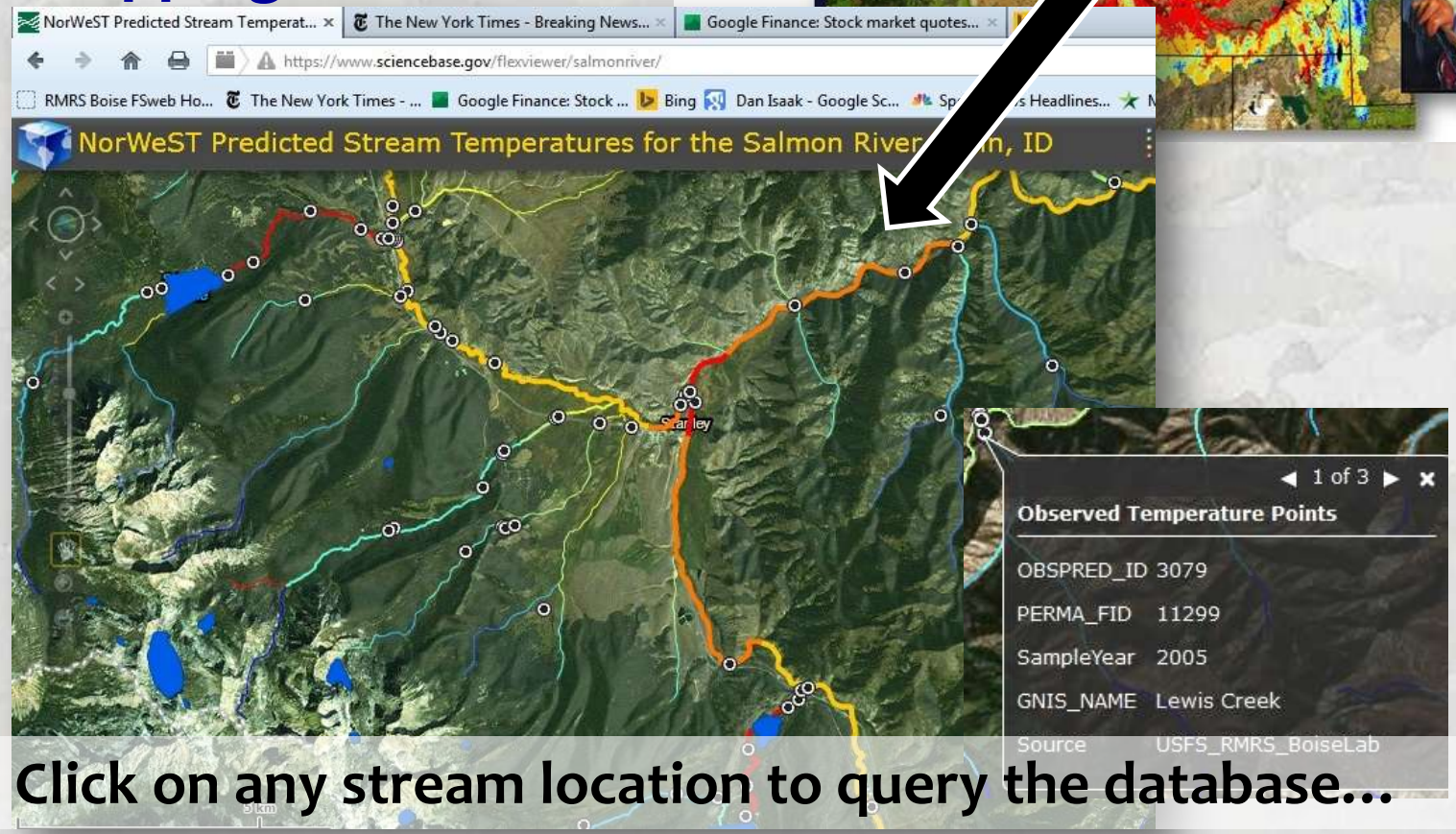
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

Web-Surf the Blob from Your Desktop!

LC MAP

Interactive Online Mapping Tool

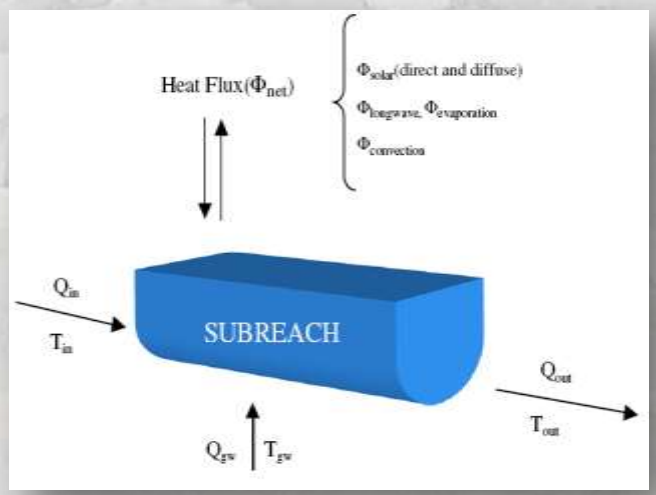


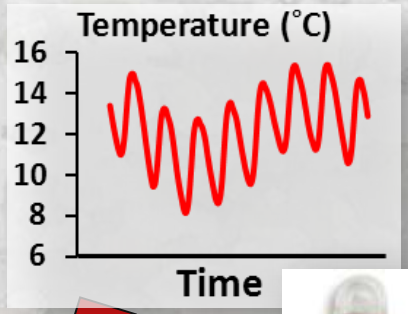


Click on any stream location to query the database…

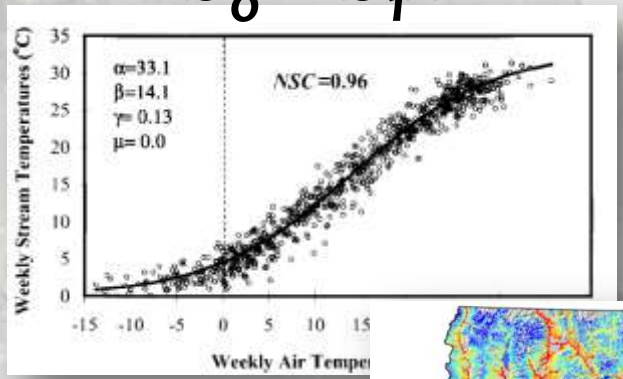
Data feeds All Models…

Mechanistic & Statistical



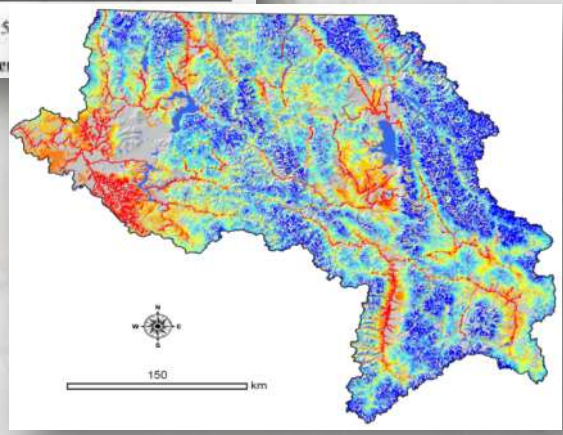


$$Y = b_o + b_1 x$$



Site

Network



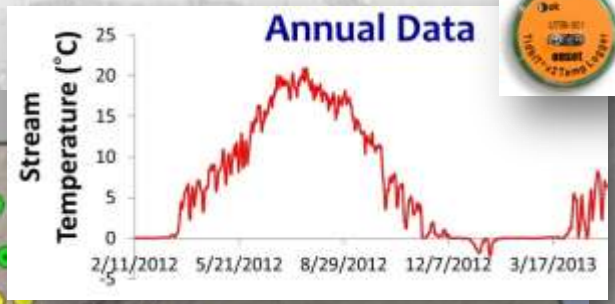
Examples…

- QUAL2Kw
- SSTEMP/SNTEMP
- BasinTemp
- Heat Source
- WET-Temp

Lots of Annual Data Coming…

>3,000 sites in Pacific Northwest

>200 new sites last year



Correlations Among Monthly Means

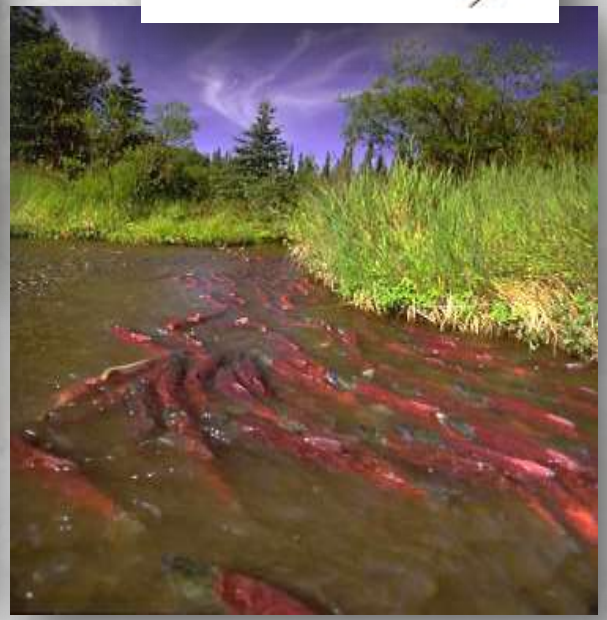
Strong Correlations Except for Winter

	Sept	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*
Oct	0.97										
Nov	0.85	0.94									
Dec	0.29	0.48	0.71								
Jan	0.34	0.47	0.63	0.79							
Feb	0.56	0.62	0.68	0.57	0.90						
March	0.89	0.94	0.96	0.62	0.67	0.78					
April	0.93	0.96	0.93	0.47	0.45	0.60	0.95				
May	0.90	0.92	0.83	0.31	0.29	0.47	0.84	0.95			
June	0.82	0.83	0.71	0.21	0.23	0.39	0.72	0.85	0.95		
July	0.87	0.84	0.75	0.15	0.21	0.42	0.72	0.82	0.88	0.91	
Aug	0.98	0.92	0.75	0.14	0.23	0.48	0.79	0.87	0.88	0.84	0.93

Non-winter months **r = 0.87**

Winter months (DJF) **r = 0.47**

The Reasons Temperature Matters…



How NorWeST data are Being Used…

NorWeST Stream Temp

Monitoring & Temperature Standards

- Interagency coordination & less redundancy
- Annual, long-term data instead of summer, short-term
- Oregon DEQ macroinvertebrate habitat indices & riparian conditions
- Total Maximum Daily Loads & site potential

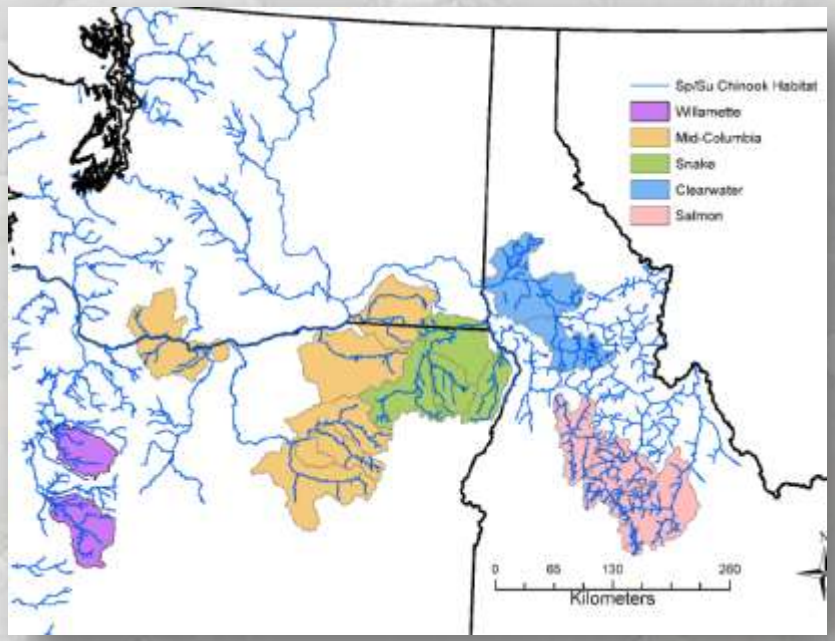
Salmon & Resident Fish Research

- Hatchery stray rates (Westerley & Dittman, U Washington)
- Pre-spawn mortality rates in Chinook salmon (Bowerman, Keefer, & Caudill, U Idaho)
- Descriptions of historical species distribution shifts (Lemoine Ph.D., U Montana)

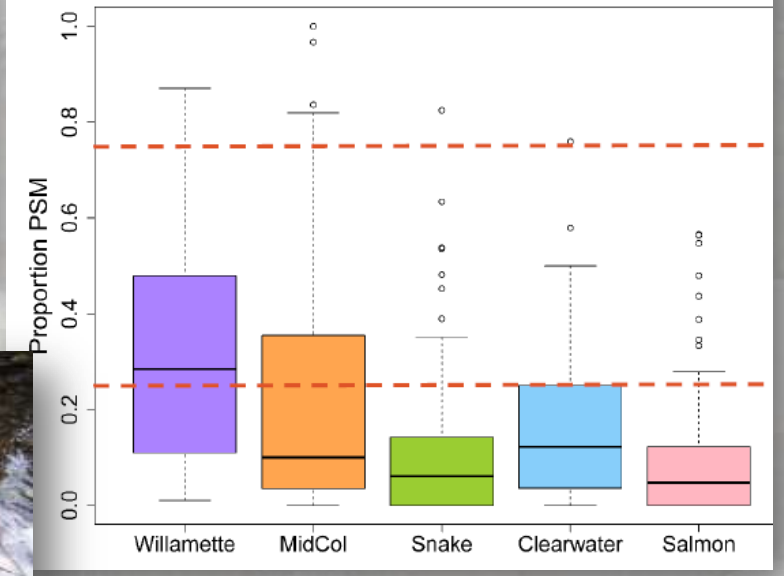
Climate Vulnerability Assessments & Land Management Planning

- Blue Mountains Adaptation Partnership, Northern Rockies Adaptation Partnership, Clearwater – EcoAdapt, etc.
- Forest Plan revisions (30 - 50 national forests) in Regions 1, 2, 4, & 6
- Southwest Crown of the Continent initiative
- Regional bull trout & cutthroat trout vulnerability assessments

NorWeST Temperature & Prespawn Mortality in Salmon

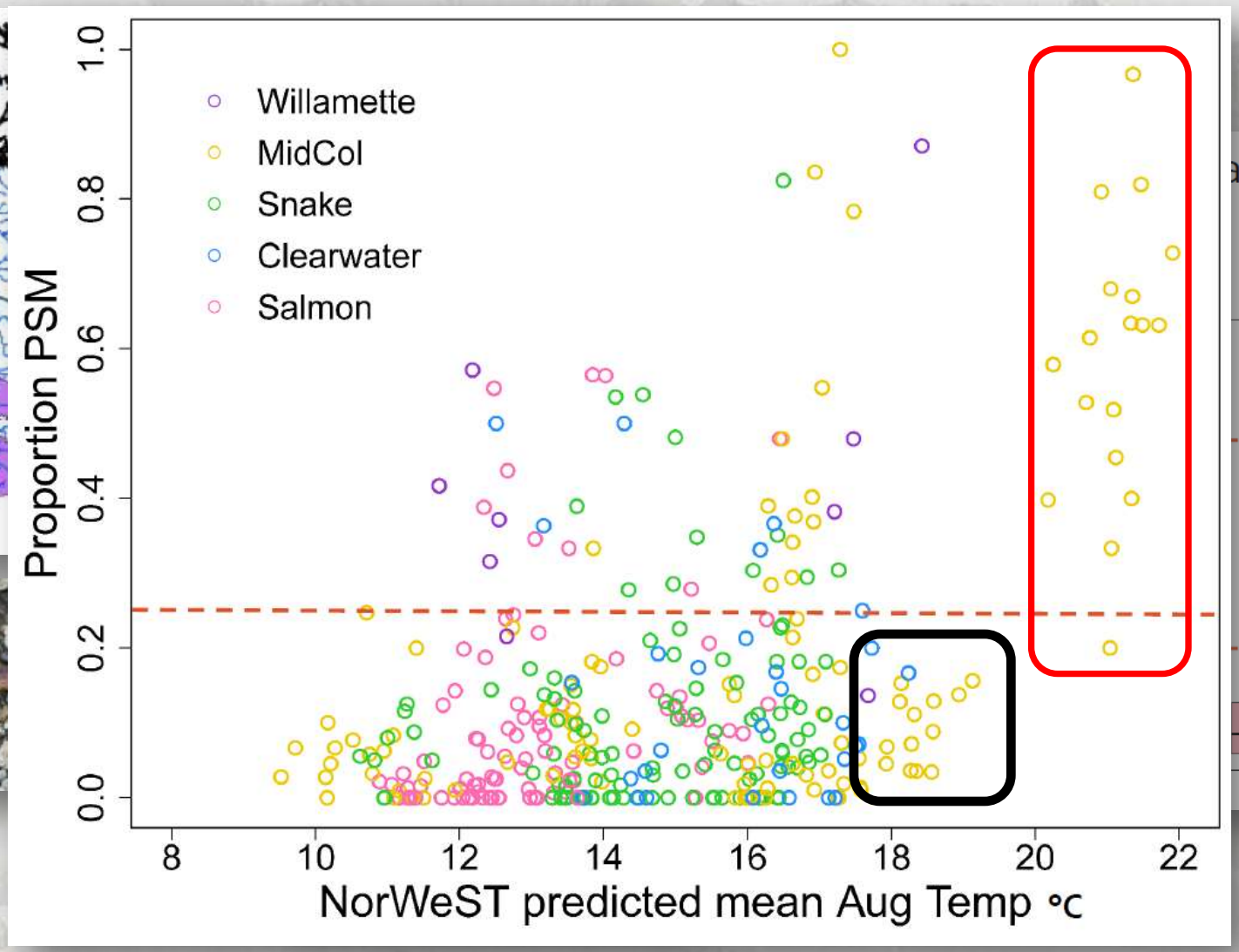


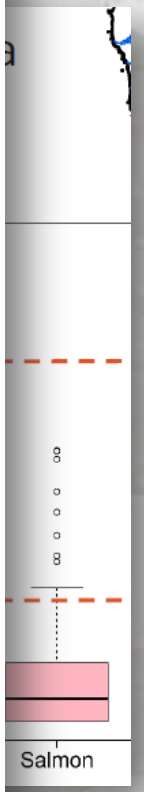
450 site years of PSM data
8 different agencies
3 ESUs



Bowerman, Keefer, & Caudill (U. Idaho)

NorWeST Temperature & Prespawn Mortality in Salmon

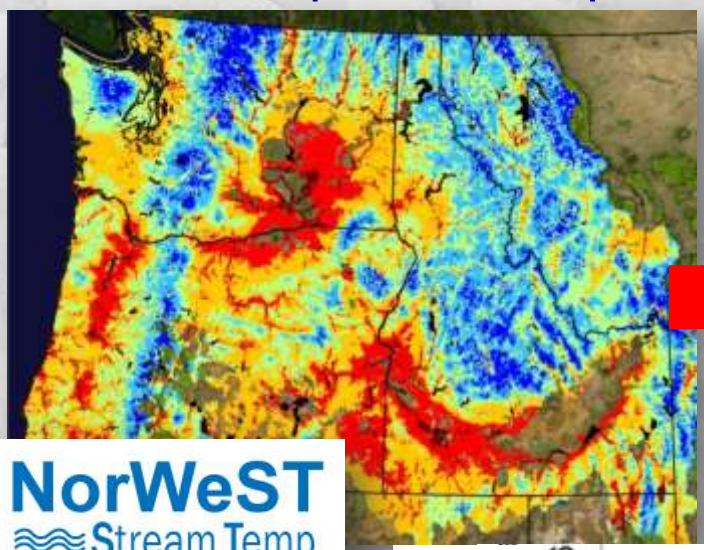




Bowerman, Keefer, & Caudill (U. Idaho)

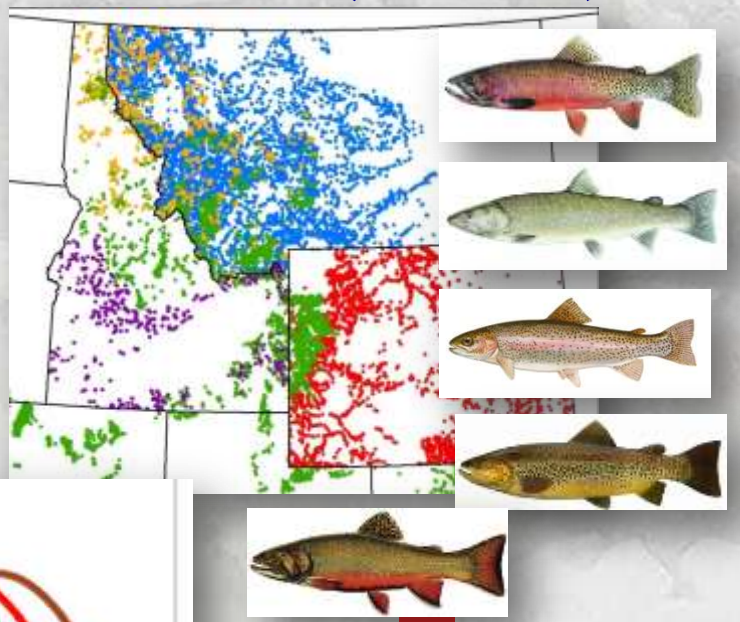
Field-Based Temperature Standards using BIG FISH Databases

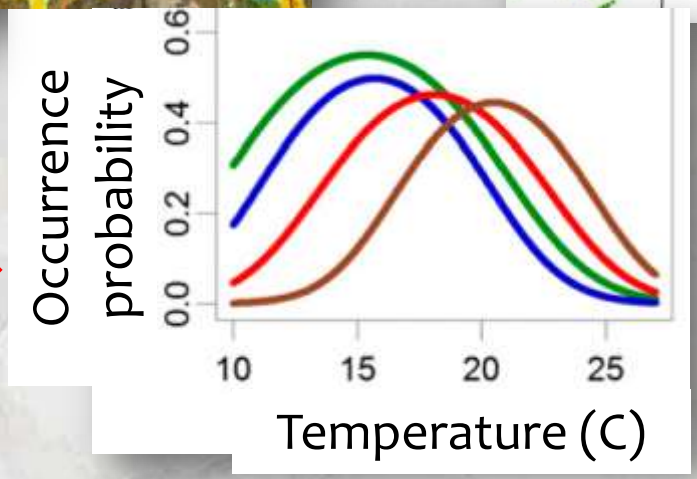
Stream temperature maps



NorWeST Stream Temp

Regional fish survey databases (n ~ 13,000)





Wenger et al. 2011a. *PNAS* **108**:14175-14180

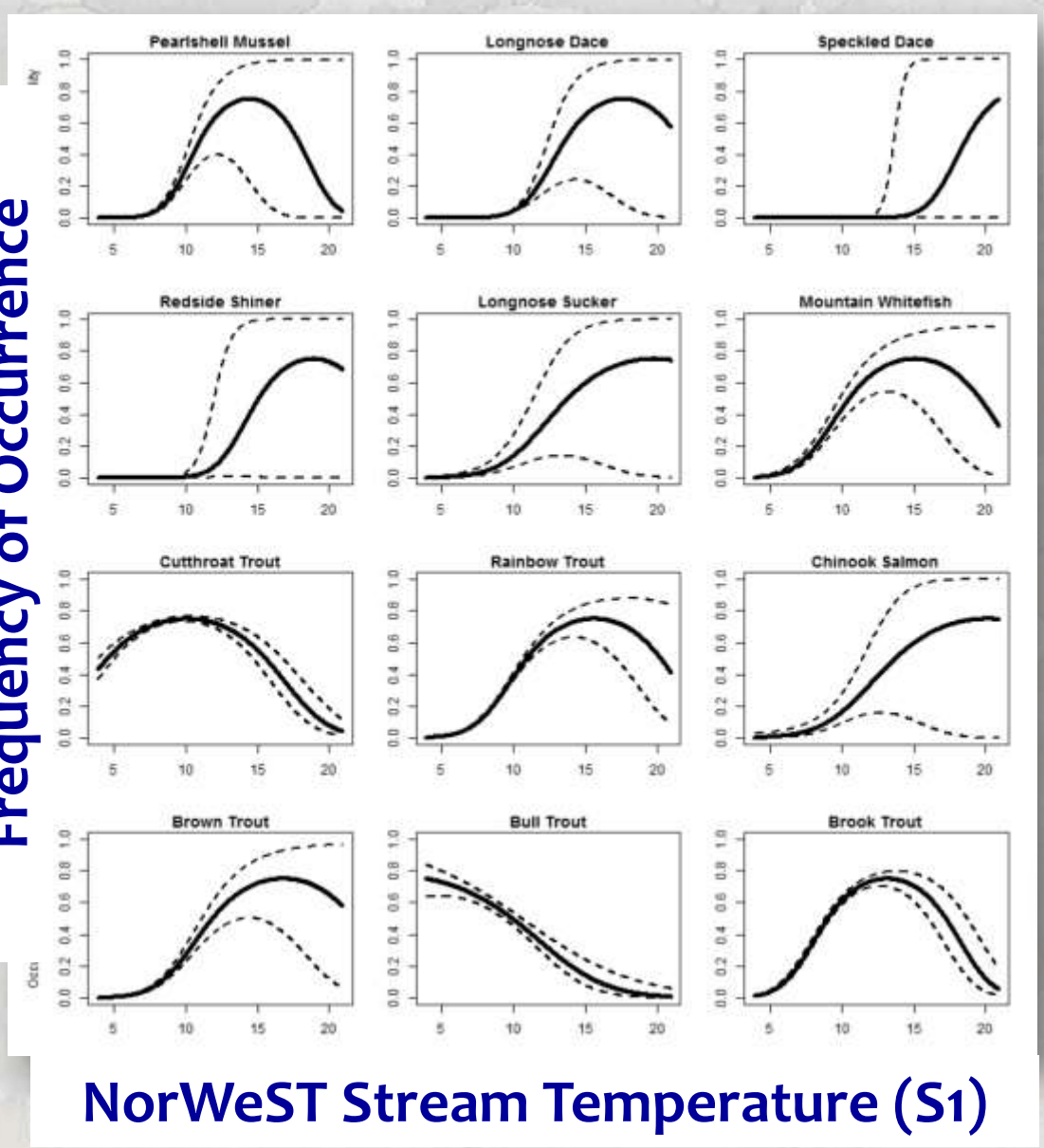
Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

A Generalizable Approach…

Just need georeferenced biological survey data

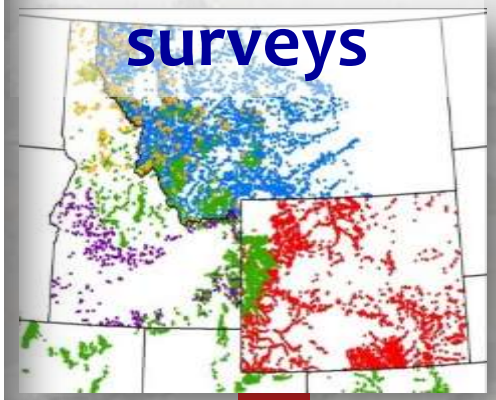
Too warm…Too cold… Just right

Thermal Niches in Batch Mode…



NorWeST Stream Temperature (S1)

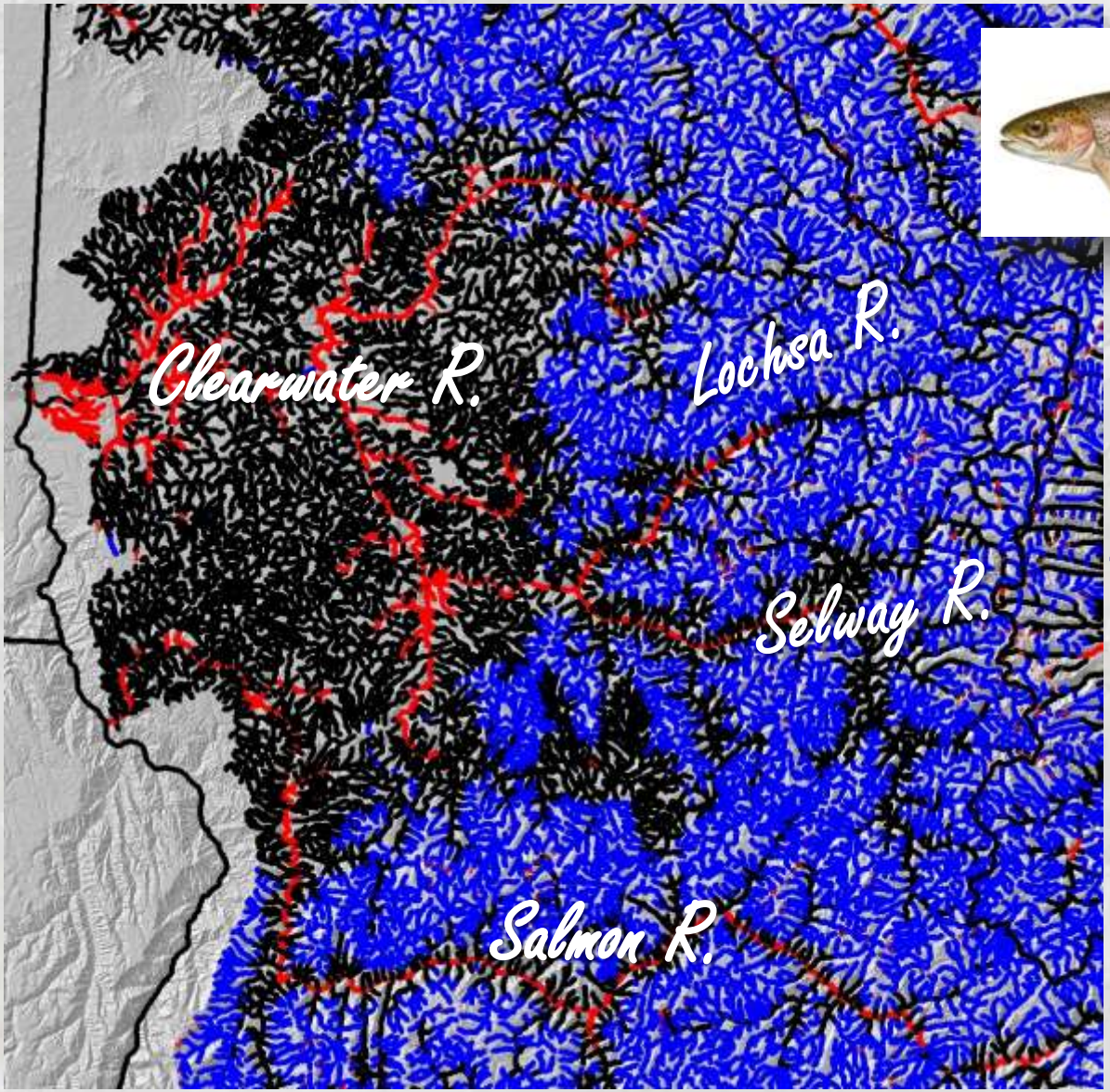
~20,000 fish surveys



Wenger et al., *In Preparation*

Climate Effects on Rainbow Thermal Habitat

Historic (1993-2011 Average August)

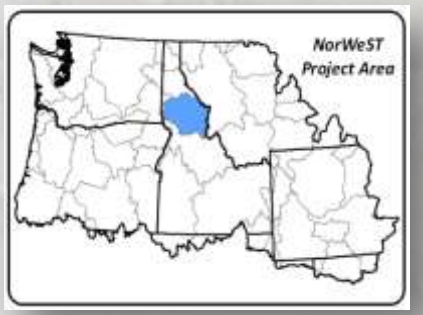


Suitable

Too Hot

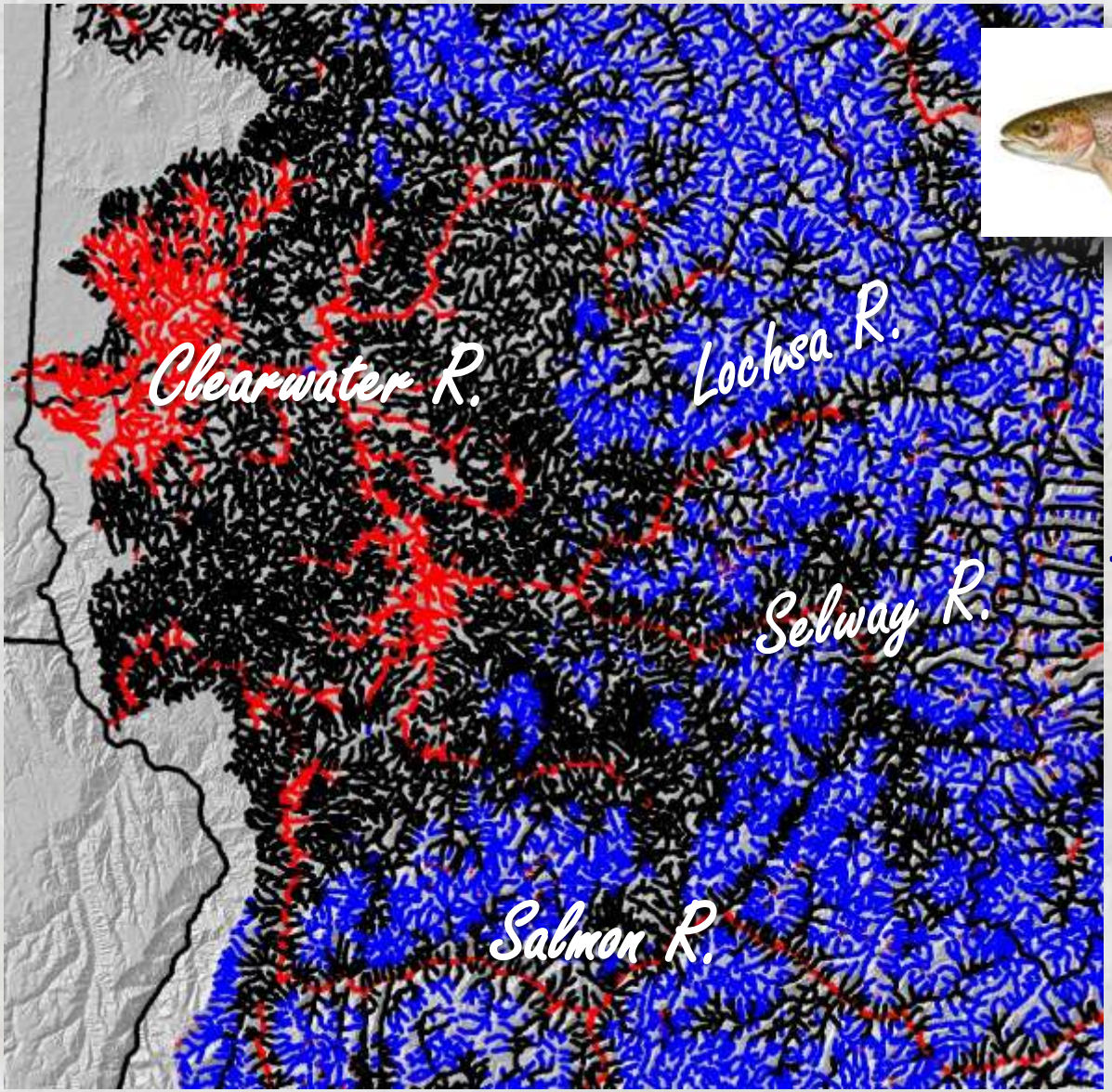
Too Cold

<17.0˚C & >11.0 ˚C



Climate Effects on Rainbow Thermal Habitat

+1.56˚C Stream Temp (~2040s)

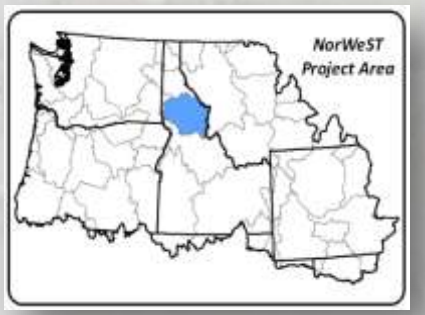


Suitable

Too Hot

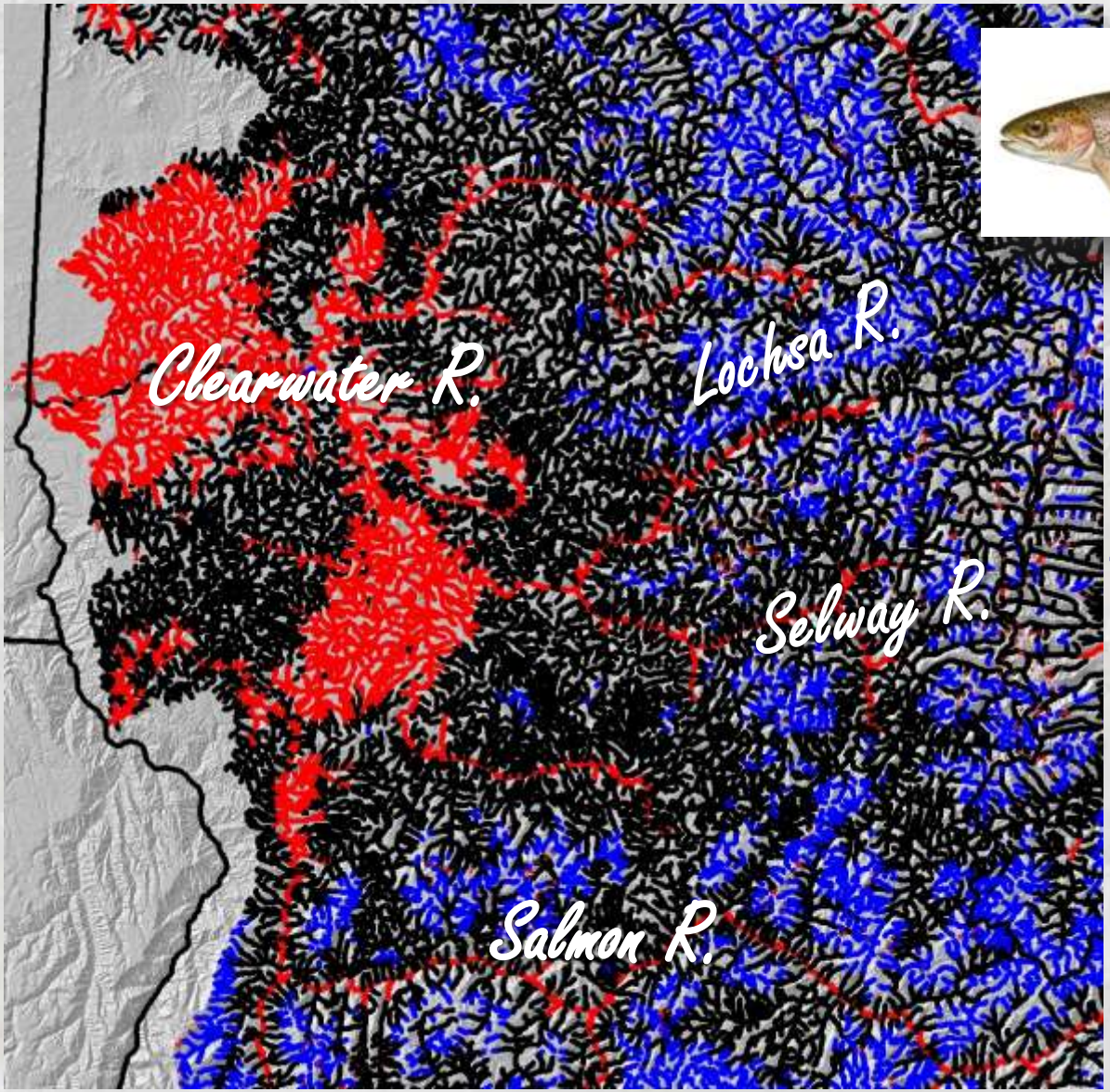
Too Cold

<17.0˚C & >11.0 ˚C



Climate Effects on Rainbow Thermal Habitat

+2.83˚C Stream Temp (~2080s)

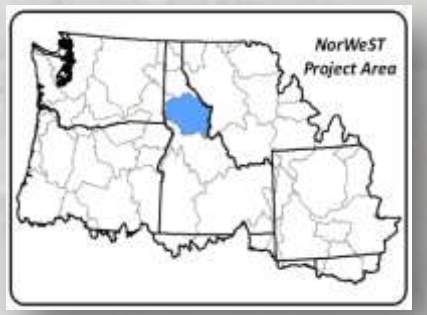


Suitable

Too Hot

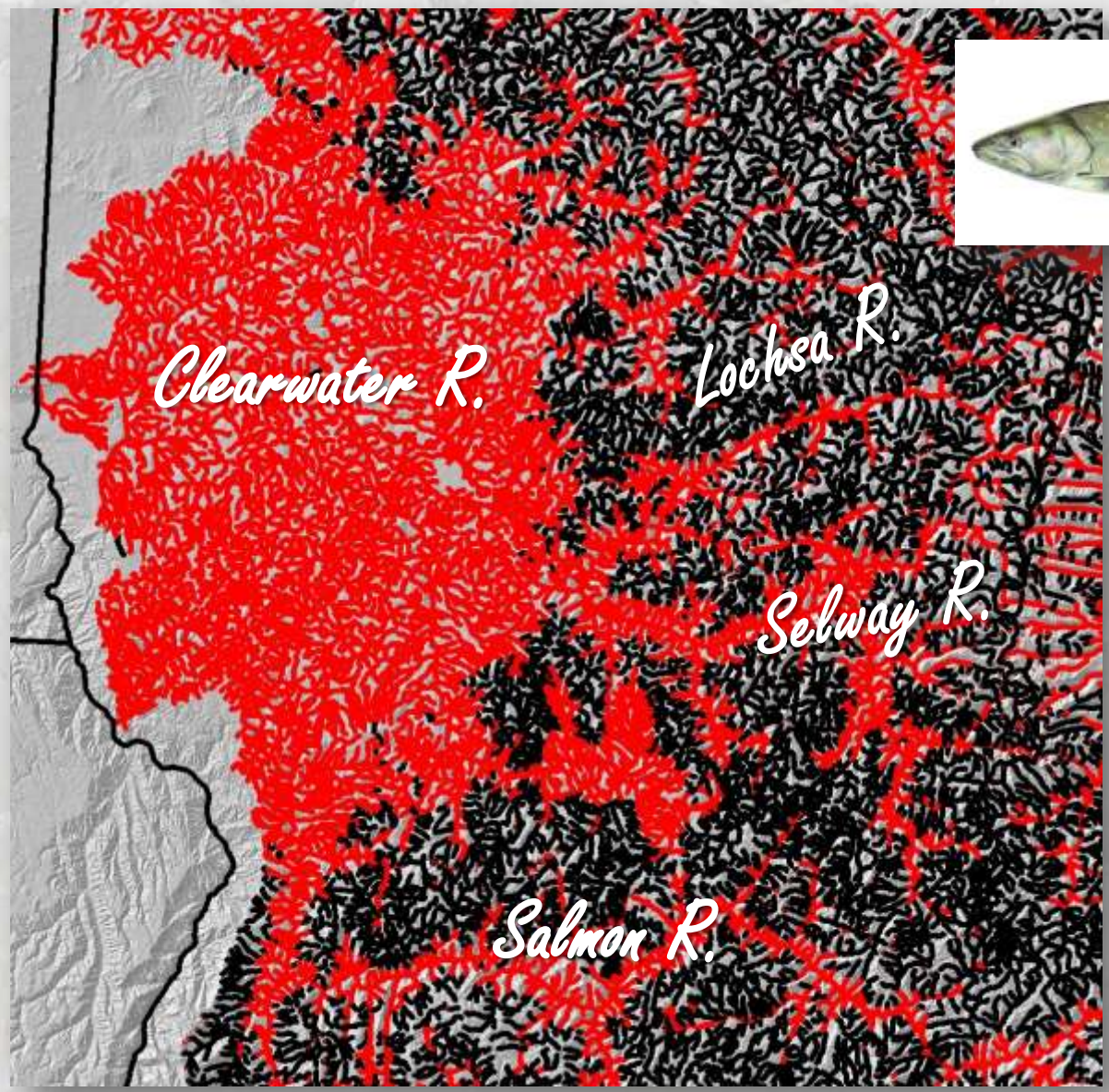
Too Cold

<17.0˚C & >11.0 ˚C



Climate Effects on Bull Trout Thermal Habitat

Historic (1993-2011 Average August)



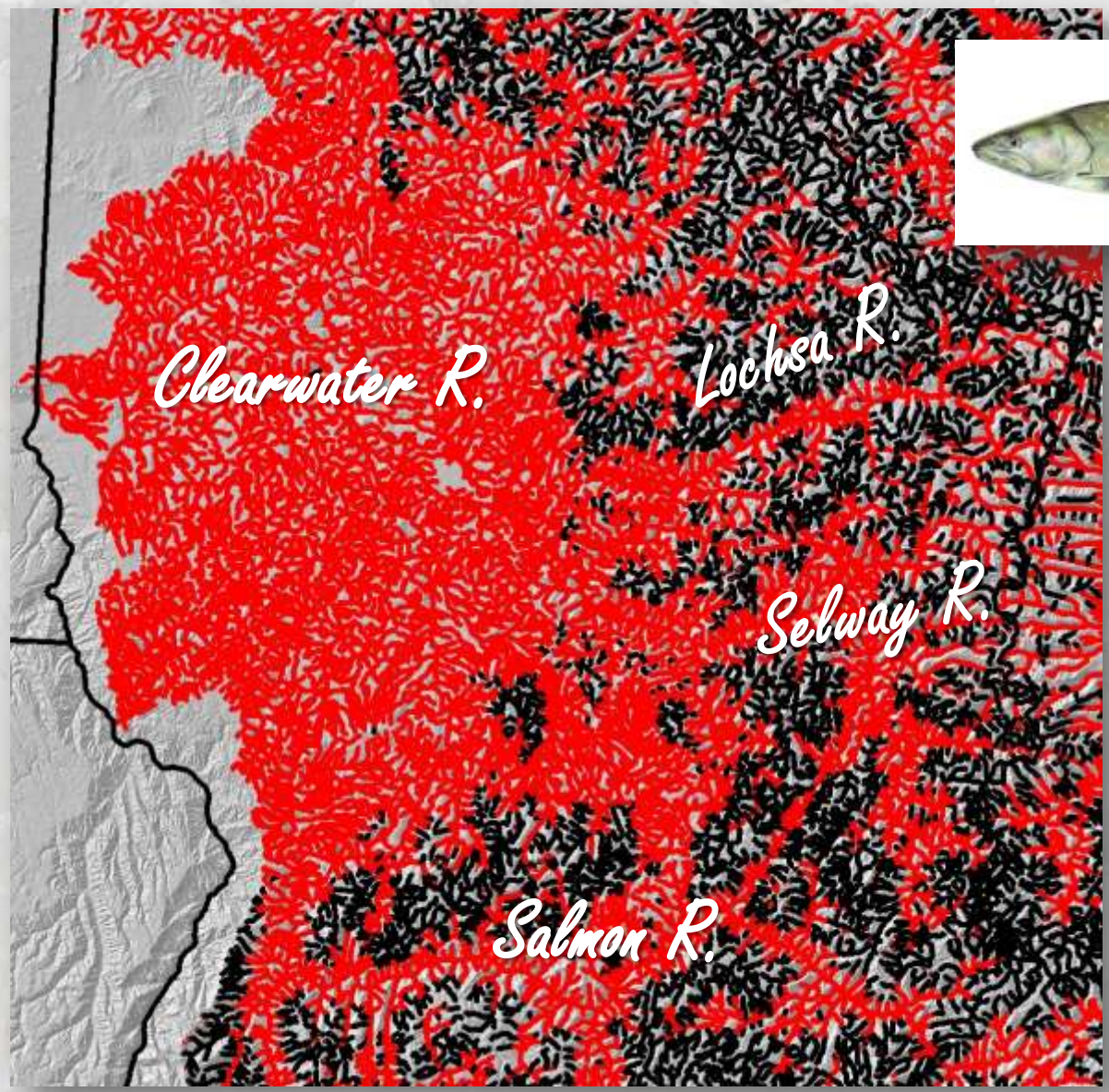
Suitable

Unsuitable

< 11.0°C

Climate Effects on Bull Trout Thermal Habitat

+1.56˚C Stream Temp (A1B, 2040s)



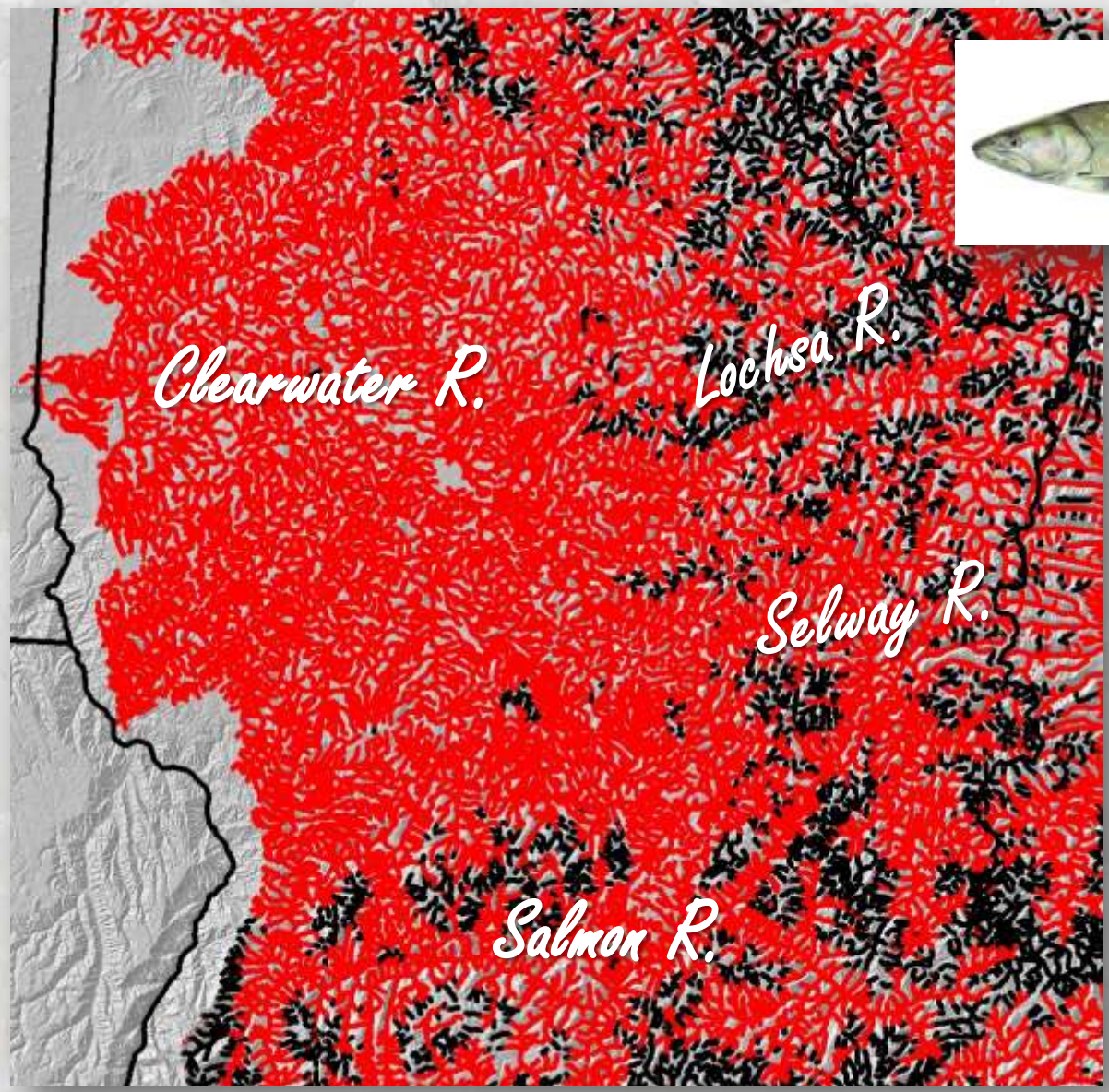
Suitable

Unsuitable

< 11.0˚C

Climate Effects on Bull Trout Thermal Habitat

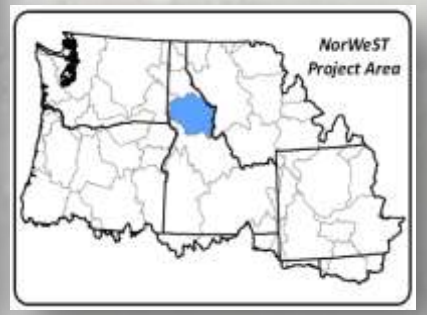
+2.83˚C Stream Temp (A1B, 2080s)



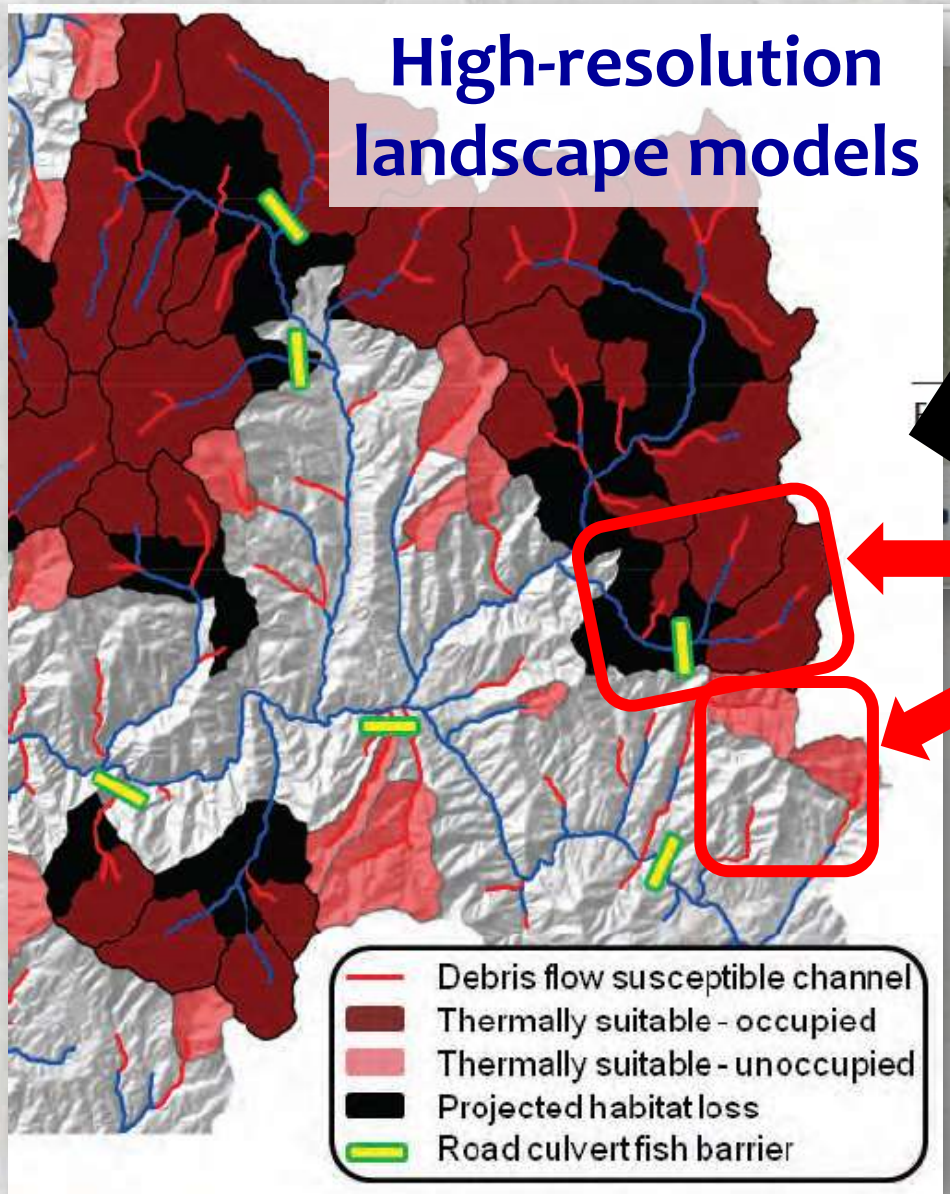
Suitable

Unsuitable

< 11.0˚C



Precise & Accurate Models Empower Local Decision Makers



NorWeST User Community…

Website launched 2.5 Years Ago

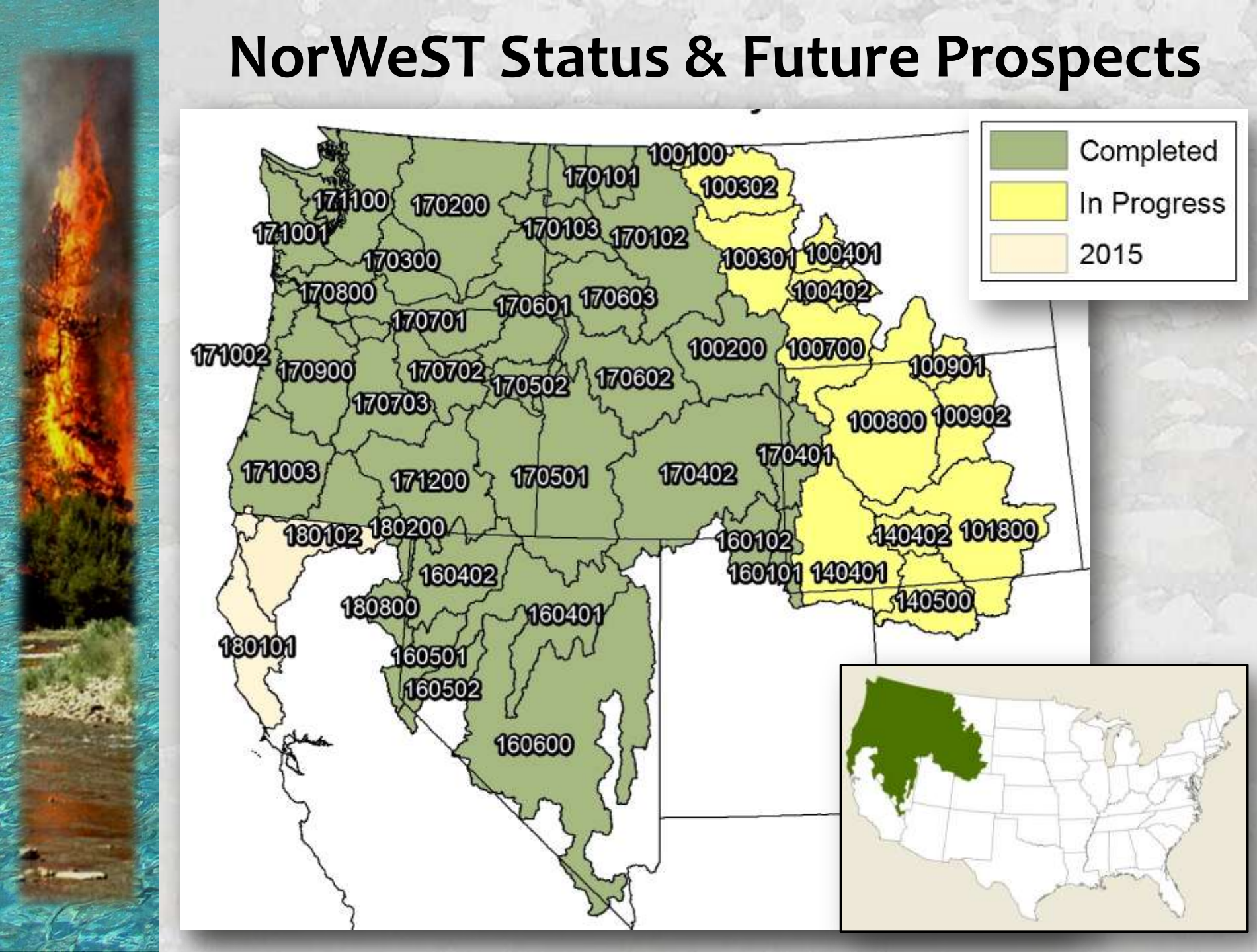
- 18,046 visits
- 1,146 downloads last 6 months

NorWeST User Community…

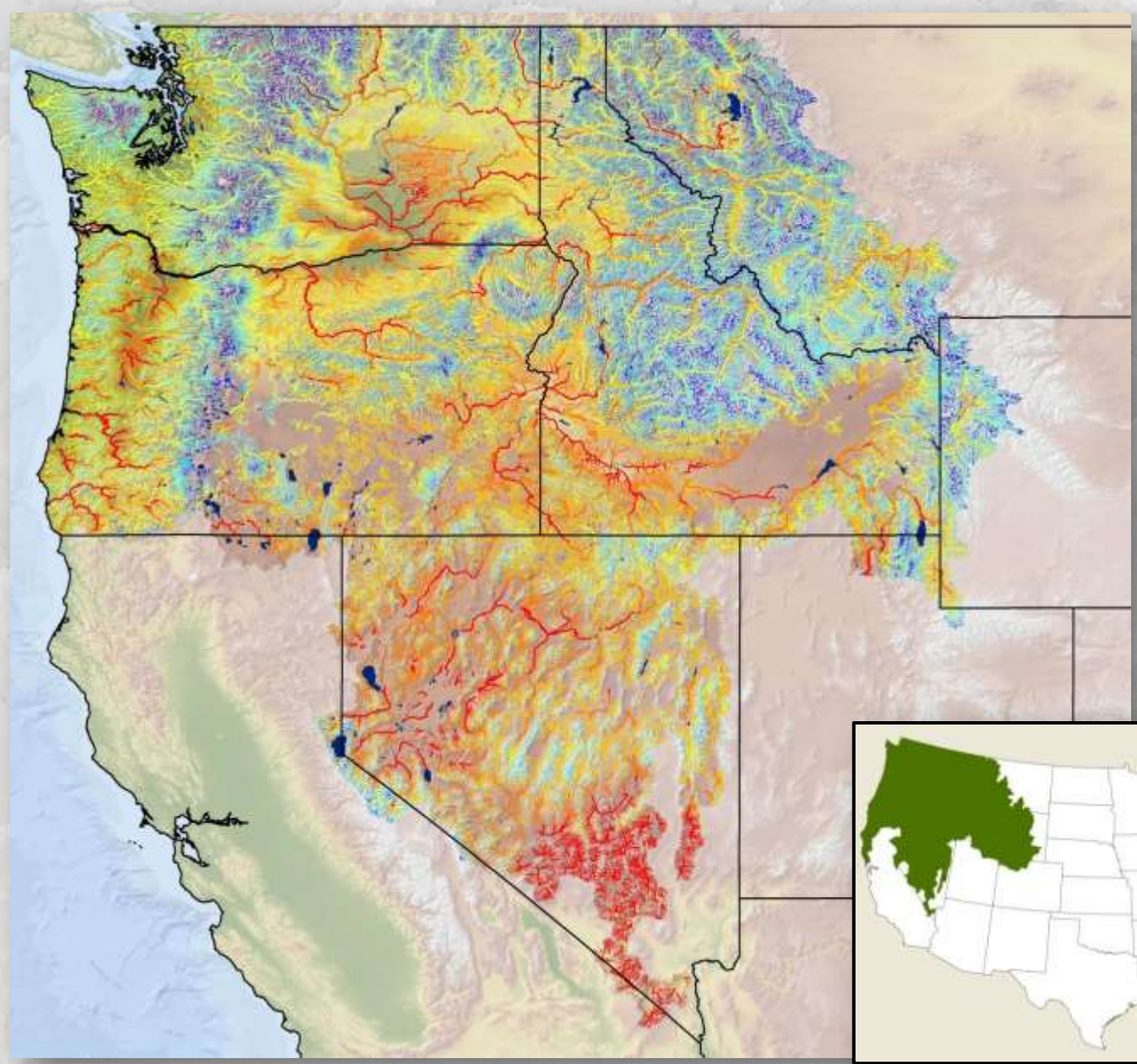
Website launched 2.5 Years Ago

- 18,046 visits
- 1,146 downloads last 6 months

NorWeST Status & Future Prospects

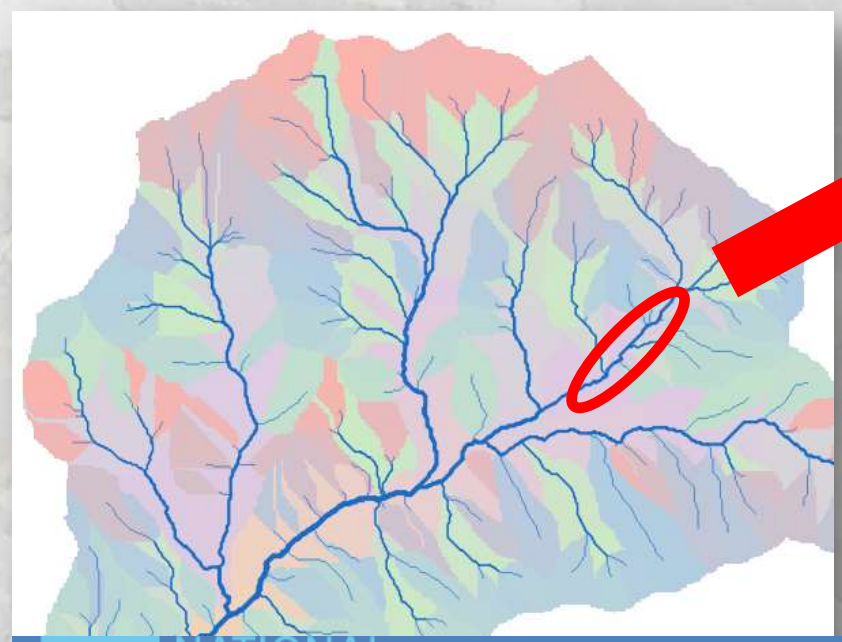


NorWeST Status & Future Prospects



Nationally consistent geospatial stream database

NHDPlus Streams



Reach Descriptors:

- Elevation
- Slope
- %Landuse
- Precipitation

100's more…

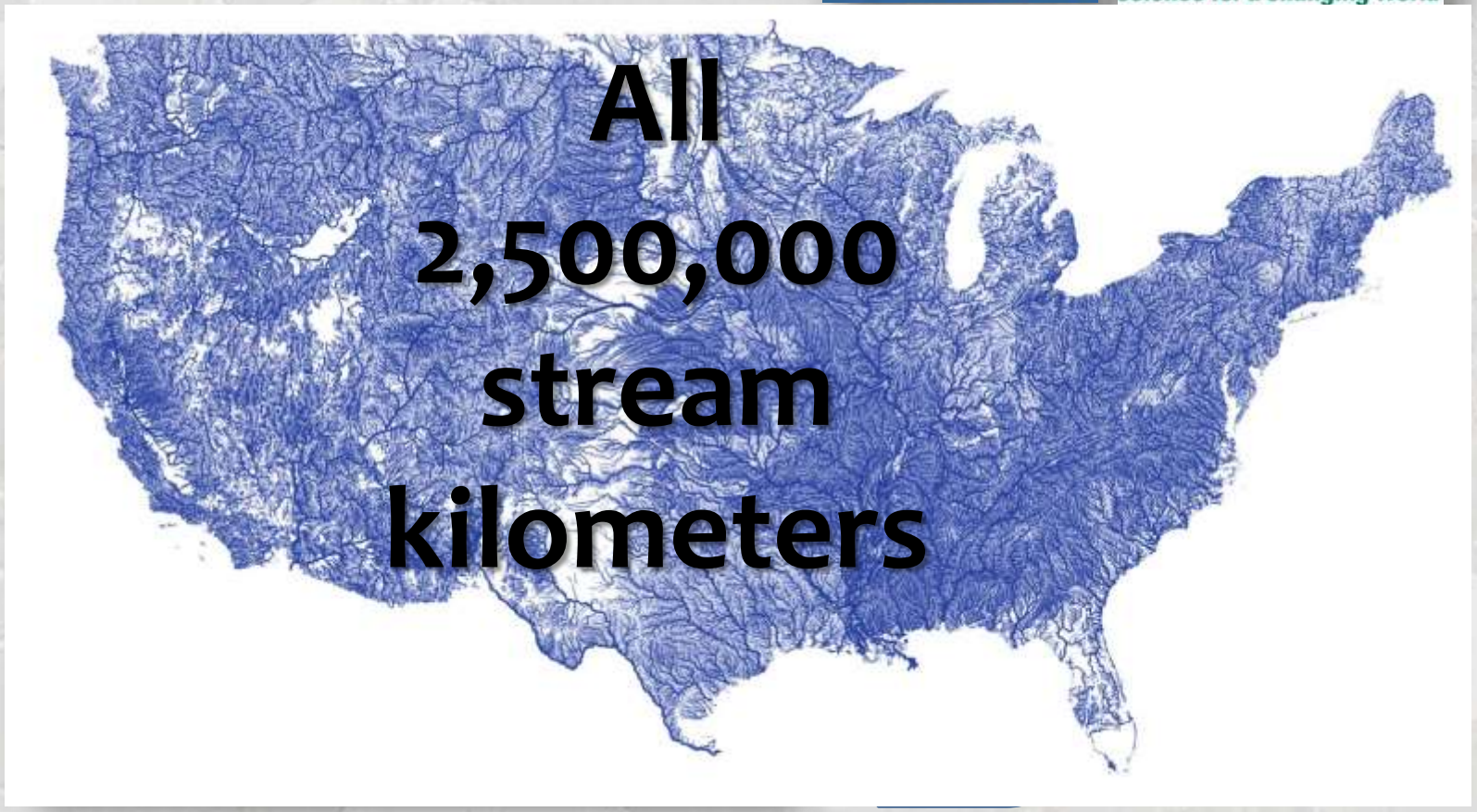
NATIONAL FISH HABITAT PARTNERSHIP

Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* **46**:510-524.

Wang et al. 2011. A Hierarchical Spatial Framework and Database for the National River Fish Habitat Condition Assessment. *Fisheries* **36**:436-449.

Nationally consistent geospatial stream database

NHDPlus Streams



Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* **46**:510-524.

Wang et al. 2011. A Hierarchical Spatial Framework and Database for the National River Fish Habitat Condition Assessment. *Fisheries* **36**:436-449.

Nationally consistent geospatial stream database

NHDPlus Streams

Cooter et al. 2010. A nationally consistent NH
waters: Implications for integrated asses
Environmental Management **46**:510-524.
Wang et al. 2011. A Hierarchical Spatial Frame
Fish Habitat Condition Assessment. *Fishe*

Thank You!

LANDSCAPE CONSERVATION COOPERATIVES

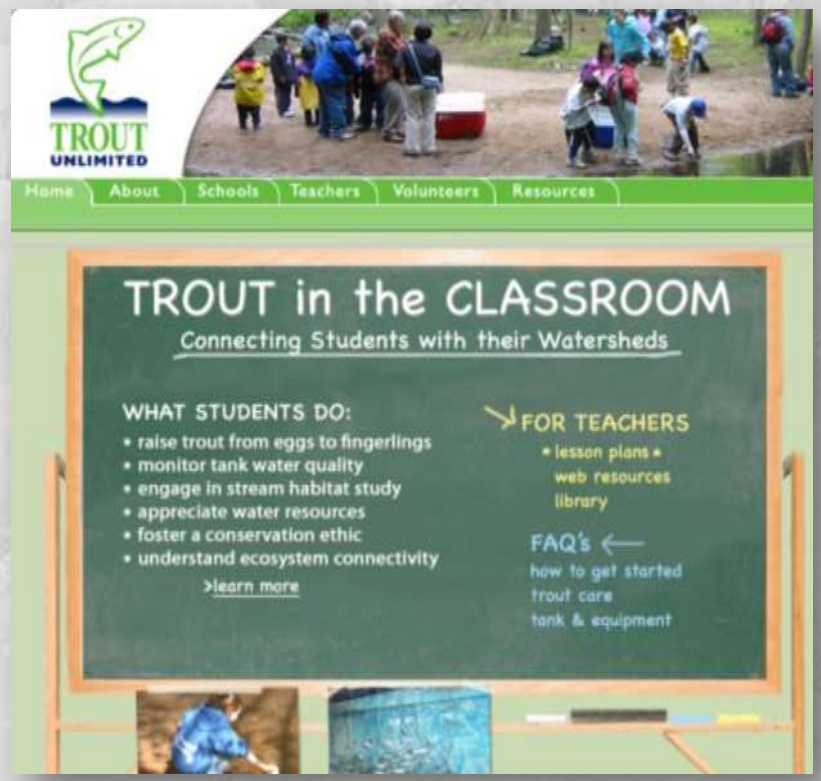
NORTH PACIFIC LANDSCAPE CONSERVATION COOPERATIVE

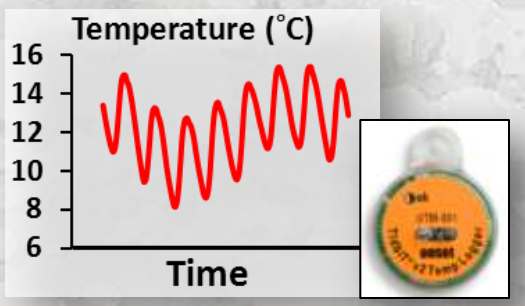
Great Northern LANDSCAPE CONSERVATION COOPERATIVE

80+ agencies & counting…

- State
- Federal
- Tribal
- Private
- Municipal
- County

Inspiring the Next Generation of Stream Climatologists…





Some school kids in 4,500 classrooms may be monitoring stream temperatures soon…